NEWNES ENGINEER'S REFERENCE BOOK

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Edited by

F. J. CAMM

Editor of "Practical Engineering"

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FOREWORD

This important book has been planned to supply the need for an up-to-date and authoritative work of reference on all branches of mechanical engineering. The great changes which have taken place during the past twenty years in workshop methods, in standardisation and machine-tool design, the introduction of new processes and materials, the higher qualifications now required of engineers, the new industries which these new materials and methods have brought about, the opportunities now provided in engineering generally, the development of engineering due to the war, the great part which mechanical engineering is expected to play in the post-war period in this country, in the export trade, and in the building industries—these are some of the reasons which have inspired the production of this new and comprehensive work.

It is agreed in the engineering industries that much of our technical reference literature has been rendered obsolescent and in many cases out-of-date by the rapid growth and development of mechanical engineering and cognate industries.

The British Standards Institution and other Institutions have during the past twenty years been actively engaged in investigating and standardising, and as a result of the work of important Technical Committees associated with these Institutions many of the former standards have been abolished and fresh standards more in keeping with modern needs have been substituted.

Manufacturers who are proprietors of particular products may, of course, still adopt their own standards, but orders executed to customer's own requirements are nowadays governed by specifications. Whilst, therefore, some of the standards have been superseded or become obsolescent they are still in use; a careful survey has been made of such standards and those which are still in use have been included in this book.

The planning of this volume has occupied my attention for several years. It has been amended from time to time as changes have taken place, and now that a stability in standardisation which is likely to last for a considerable time has been attained, it is felt by the publishers that the time is opportune to produce it. My work has been augmented by that of specialist contributors, separately acknowledged.

A glance at the list of contents will reveal the truly comprehensive nature of this work. Enormous effort has been made to bring within the covers of one volume the information and reference which at present is scattered through numbers of volumes. Specialists in various branches of engineering have added their knowledge in the form of specially con-

tributed sections, and the whole book is welded together by means of an extensive and fully cross-referenced index. A team of draughtsmen expert in the production of technical drawings have prepared the illustrations throughout.

It will be seen from the list of contributors that every effort has been made to ensure an authoritative work free from overlapping, complete and exhaustive. It is confidently expected that the work will be accepted as a standard in an industry where standards are the order of the day. Suggestions for future editions will be welcomed.

F. J. CAMM.

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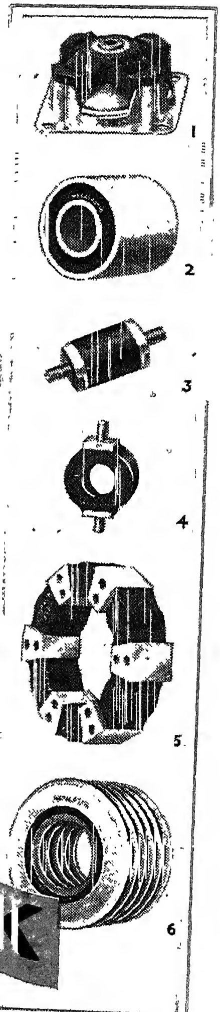

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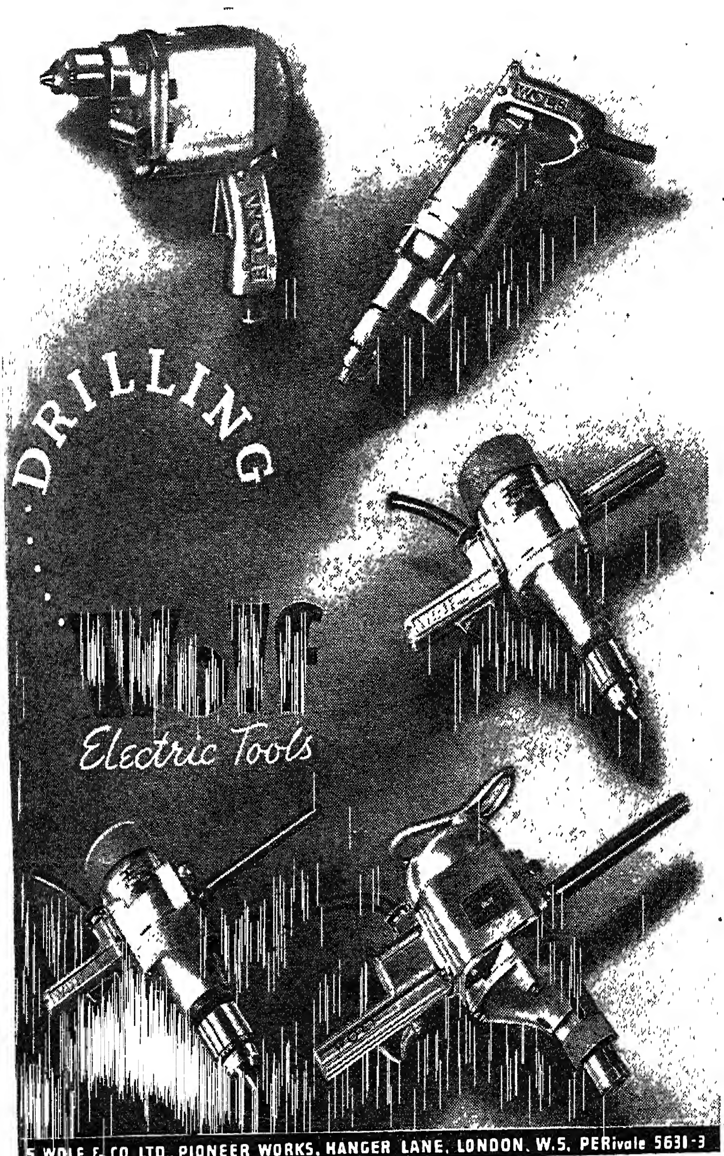
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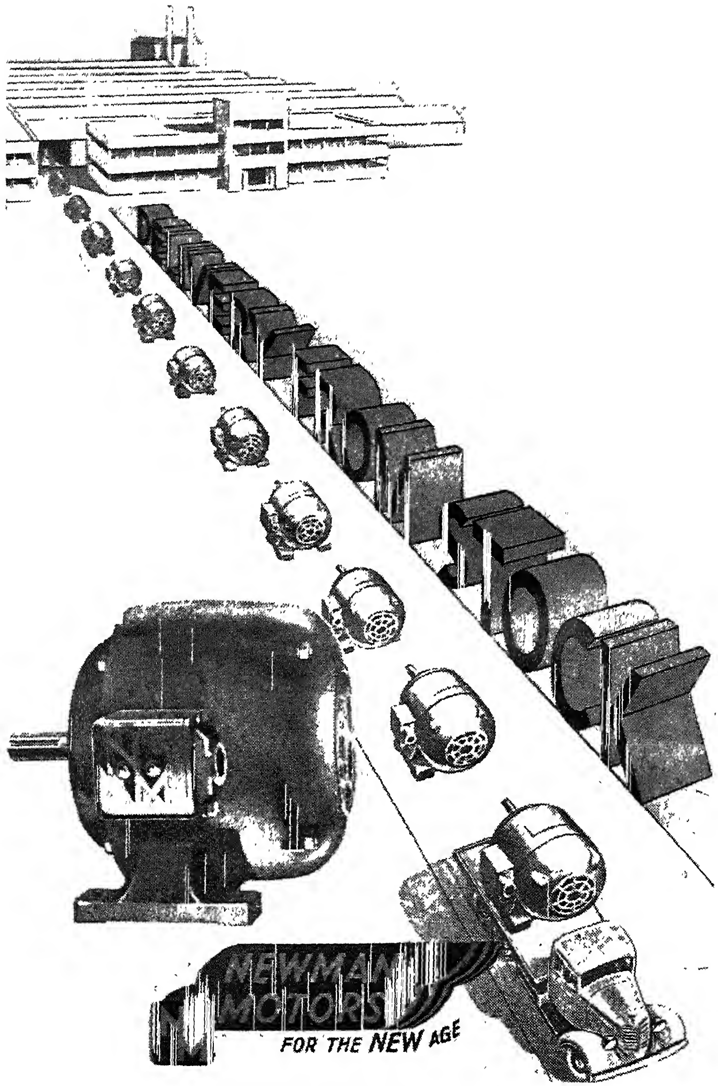
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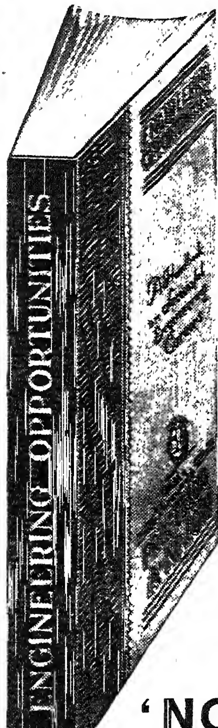

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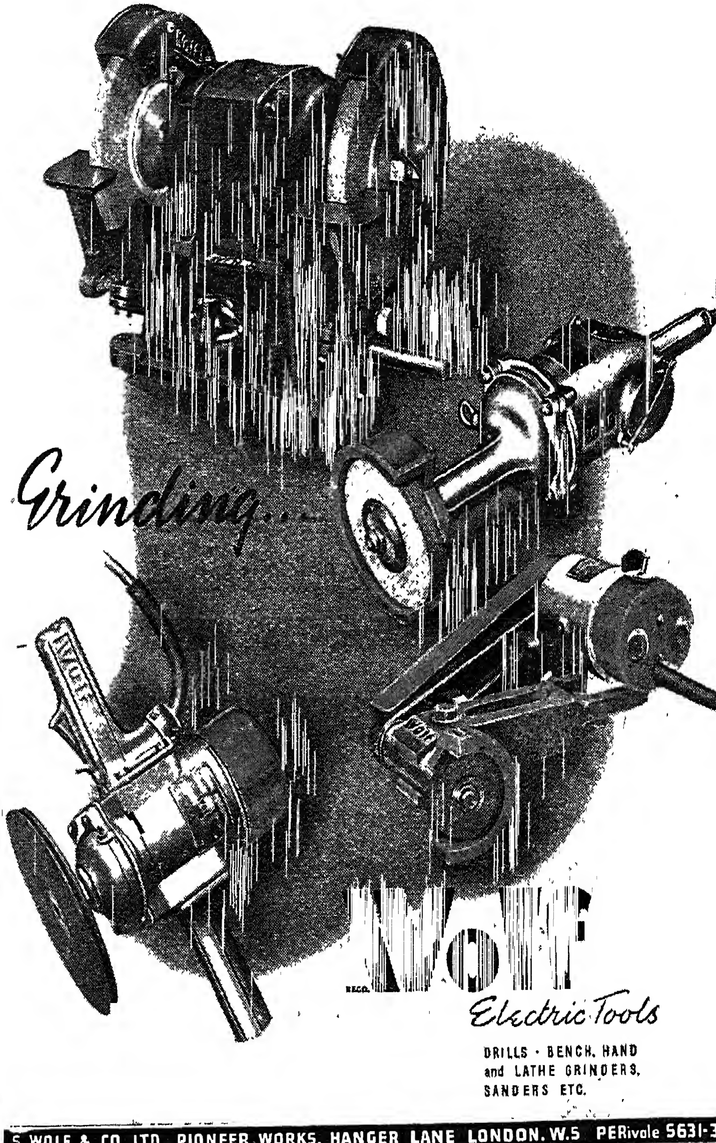
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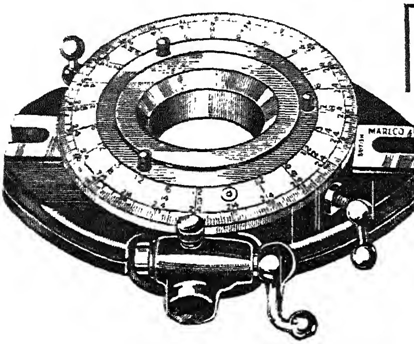

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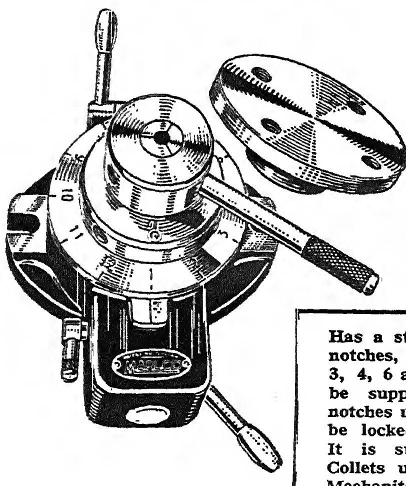

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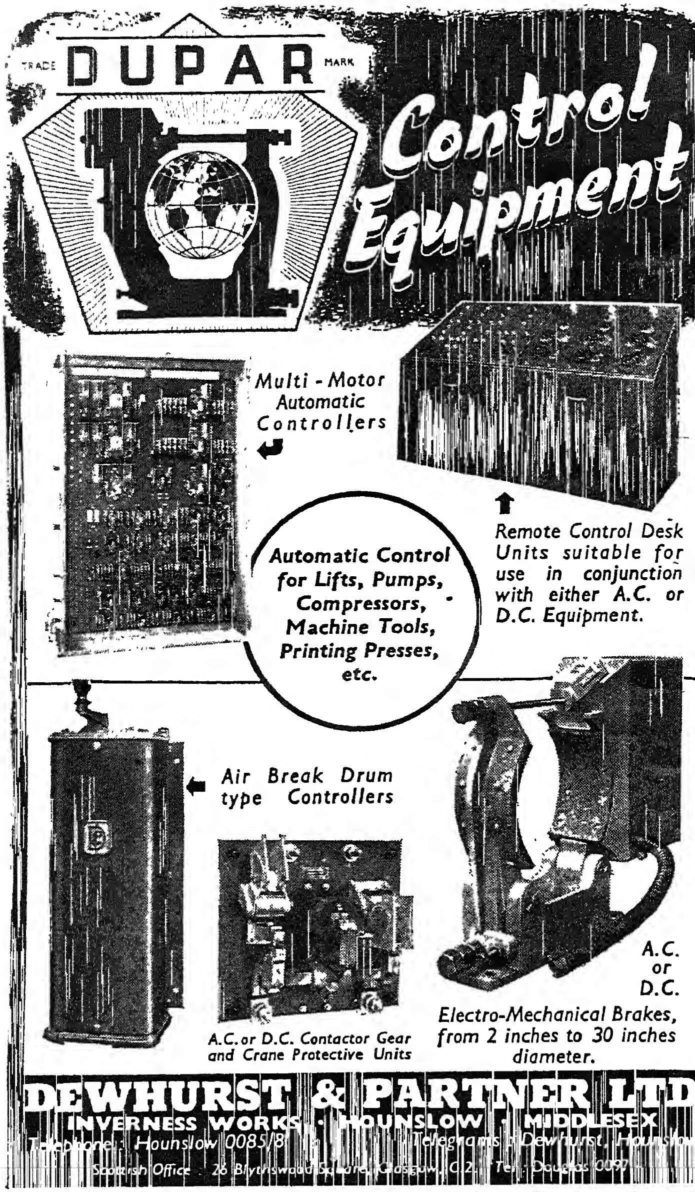

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STANDARD ABBREVIATIONS

A

A.C.	Alternating current, or air-cooled.
A.C.G.I.	Associate of the City and Guilds of London Institute.
Ae.	Aerial, or aeronautical.
A.E.S.D.	Association of Engineering and Shipbuilding Draughtsmen.
A.E.U.	Amalgamated Engineering Union.
A.F.	Audio frequency.
A.F.C.	Automatic frequency control.
A.F.R.Ae.S.	Associate Fellow of the Royal Aeronautical Society.
A.G.C.	Automatic gain control.
A.H.P.	Actual horse-power.
A.I.D.	Aeronautical Inspection Directorate.
A.M.	Amplitude modulation.
A.M.I.A.E.	Associate Member of the Institution of Automobile Engineers.
A.M.I.C.E.	Associate Member of the Institution of Civil Engineers.
A.M.I.E.E.	Associate Member of the Institution of Electrical Engineers.
A.M.I.M.E.	Associate Member of the Institution of Mechanical Engineers.
A.M.I.Min.E.	Associate Member of the Institute of Mining Engineers.
A.S.	Academy of Science.
A.S.A.	American Standards Association.
A.S.C.E.A.	American Society of Civil Engineers and Architects.
A.S.M.E.	American Society of Mechanical Engineers.
A.Sc.	Associate in Science.
A.S.S.E.T.	Association of Supervisory Staffs and Engineering Technicians.
A.T.C.	Aerial tuning condenser.
A.T.I.	Aerial tuning inductance.
At. wt.	Atomic weight.
A.V.C.	Automatic volume control.
A.V.E.	Automatic volume expansion.
A.W.G.	American wire gauge.

B

B. & S.	Brown & Sharpe.
B.A.	Bachelor of Arts, or British Association.
B/D or Brd.	Braided.
B.D.C.	Bottom dead centre.
B.Eng.	Bachelor of Engineering.
B.E.S.A.	British Engineering Standards Association (obsolete, see B.S.I.).
B.F.O.	Beat frequency oscillator.
B.G.	Birmingham gauge.
B.H.P.	Brake horse-power.
B.Sc.	Bachelor of Science.
B.Sc.Eng.	Bachelor of Faculty of Engineering (London University).
B.S.F.	British Standard Fine.
B.S.I.	British Standards Institution.
B.S.P.	British Standard Pipe.
B.S.S.	British Standard Specification.
B.S.W.	British Standard Whitworth.
B.Th.U.	British Thermal Unit.
B.T.U.	Board of Trade Unit = 1,000 watt-hours, or 1 kilowatt-hour.
B.W.G.	Birmingham wire gauge (obsolete, see B.G.).

C

Car.	Carat.
C.C.	Cubic centimetre.
C.C.C.	Closed circuit (or secondary) condenser.
C.C.I.	Closed circuit, or secondary tuning, inductance (S.T.I.).
C.	Centigrade.
C.E.	Chief engineer, or civil engineer.
C.G.	Centre of gravity.
C.G.S.	Centimetre-gramme-second.
C.H.U.	Centigrade heat unit.
C.I.	Cast iron, or compression ignition.
Cir.	Circumference.
C./L.	Centre line.
Cm.	Centimetre.
Compd. strand	Compressed strand.

C.P. . . Candle power, or centre of pressure.
Csk. . . Countersink or countersunk.
C.S. . . Cast steel, or carbon steel.
C. of T. . Centre of thrust.
C.W. . Continuous waves.
Cwt. . . Hundredweight.

D

D.A.V.C. . Delayed automatic volume control.
Db. . . decibel.
D.C. . . Direct current.
D.C.C. . Double cotton covered.
D.E. . Dull emitter.
D.Eng. . Doctor of Engineering.
D.F. . . Direction finding, or direction finder.
Dg. . . Decigram.
Dia. . . Diameter.
D.I.R. or D.P.R. . Double lapping of pure rubber.
Dl. . . Decilitre.
Dm. . . Decimetre.
D.O. . Drawing office.
D.P. . . Difference of potential.
D.P.C. . Double paper covered.
D.P.D.T. . Double pole double throw.
D.P.S.T. . Double pole single throw.
Drg. . . Drawing.
D.Sc. . Doctor of Science.
D.S.C. . Double silk covered.
D.T.D. . Directorate of Technical Developments.
D.W.S. . Double white silk.
Dwt. . Pennyweight.
Dx. . . Long distance.
Dyn. . Dynamic.

E

E. . . Earth.
E.M.F. . Electromotive force.
Enam. . Enamelled.
Enam. & D.C.C. . Enamelled and double cotton covered.
Enam. & D.S.C. . Enamelled and double silk covered.
Enam. & S.C.C. . Enamelled and single cotton covered.
Enam. & S.S.C. . Enamelled and single silk covered.

F

F. . . Filament.
F.C.G.I. . Fellow of the City and Guilds of London Institute.
F.M. . Frequency modulation.
F.R.Ae.S. . Fellow of the Royal Aeronautical Society.
F.R.S. . Fellow of the Royal Society.
F.R.S.A. . Fellow of the Royal Society of Arts.
Ft. . . Foot.
Ft.-lb. . Foot-pound.
Fur. . Furlong.
F.W.A. . Factories and Workshops Act.

G

G. . . Gravity, or grid.
Gal. . . Gallon.
G.B. . . Grid battery, or grid bias.
G.C. . . Grid condenser.
G.L. . . Grid leak.
Gr. . . Grain.
Grm. . Gram or gramme.

H

H.C. . . High conductivity.
H.D. . Hard drawn.
H.F. . High frequency (same as radio frequency).
H.F.C. . High-frequency choke.
Hl. . . Hectolitre.
Hm. . . Hectometre.
H.P. . Horse-power.
H.R. . High resistance.
H.S.S. . High-speed steel.
H.T. . High tension.
H.T.S. . High-tensile steel.

I

I.A.E. . Institution of Automobile Engineers.
I.C. . . Intermittent current.
I.C.E. . Institution of Civil Engineers, or internal-combustion engine.
I.C.W. . Interrupted continuous waves.
I.E.E. . Institution of Electrical Engineers.
I.E.I. . Institute of Engineering Inspection.
I.F. . . Intermediate frequency.
I.H.P. . Indicated horse-power.
I.M.T. . Institute of the Motor Trade.
In. . . Inch.
I.P. . . In primary (of transformer); start of primary.

Deflection at centre of span:

$$\frac{Wl^3}{192EI}.$$

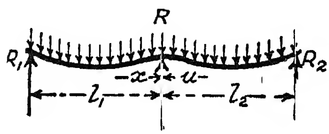
Deflection at point of greatest negative stress at:

$$x = \frac{5}{8}l \text{ is } \frac{Wl^3}{187EI}.$$

Example 22

Between R_1 and R:

$$s = \frac{l_1 - x}{Z}\left\{\frac{(l_1 - x)W_1}{2l_1} - r_1\right\}.$$



Continuous beam with two unequal spans, unequal uniform loads.

$$\frac{{}_1w_1(3l_1 + 4l_2) - w_2l_2^2}{8l_1(l_1 + l_2)} \qquad \frac{l_2w_2(3l_2 + 4l_1) - w_1l_1^2}{8l_2(l_1 + l_2)}$$

$$\left(\frac{w_1 + w_2}{2}\right) + \frac{1}{8}\left(\frac{w_1l_1}{l_2} + \frac{w_2l_2}{l_1}\right)$$

Between R_2 and R:

$$s = \frac{l_2 - u}{Z}\left\{\frac{(l_2 - u)W_2}{2l_2} - r_2\right\}.$$

Stress at support R:

$$\frac{W_1l_1^2 + W_2l_2^2}{8Z\,(l_1 + l_2)}.$$

Greatest stress in the first span is at:

$$x = \frac{l_1}{W_1}(W_1 - r_1) \text{ and is}$$

$$= \frac{r_1^2\,l_1}{2ZW_1}.$$

Greatest stress in the second span is at:

$$u = \frac{l_2}{W_2}\,(W_2 - r_2)$$

and is:

$$-\frac{r_2^2l_2}{2ZW_2}.$$

Between R_1 and R:

$$y = \frac{x(l_1 - x)}{24EI}\left\{(2l_1 - x)\,(4r_1 - W_1) - \frac{W_1\,(l_1 - x)^2}{l_1}\right\}.$$

Between R_2 and R:

$$y = \frac{u(l_2 - u)}{24EI}\left\{(2l_2 - u)\,(4r_2 - W_2) - \frac{W_2\,(l_2 - u)^2}{l_2}\right\}.$$

This case, given by Example 22, is so complicated that convenient general xpressions for the maximum deflections cannot be obtained.

Example 23

Between point A and load:

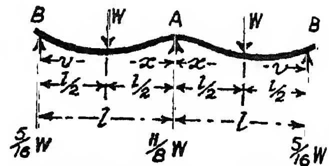
$$s = \frac{W}{16Z}(3l - 11x).$$

Between point B and load:

$$= -\frac{5}{16}\frac{Wv}{Z}.$$

Maximum stress at point A:

$$\frac{3}{16}\frac{Wl}{Z}.$$



Continuous beam, with two unequal spans; equal loads at centre of each.

Stress is zero at:

$$x = \frac{3}{11}l.$$

Greatest negative stress at centre of span:

$$-\frac{5}{32}\frac{Wl}{Z}.$$

Between point A and load:

$$y = \frac{Wx^2}{96EI}(9l - 11x).$$

Between point B and load:

$$y = \frac{Wv}{96EI}(3l^2 - 5v^2).$$

Maximum deflection is at $v = 0{\cdot}4472\,l$, and is:

$$\frac{Wl^3}{107{\cdot}33EI}.$$

Deflection at load:

$$\frac{7}{768}\frac{Wl^3}{EI}.$$

Example 24

Between R_1 and W_1:

$$s = -\frac{wr_1}{Z}.$$

Between R and W_1:

$$s = \frac{I}{l_1Z}[m(l_1 - u) - W_1a_1u].$$

Between R and W_2:

$$s = \frac{I}{l_2Z}[m(l_2 - x) - W_2a_2x]$$

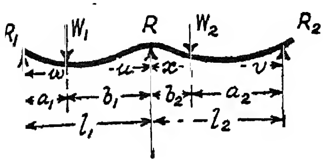
Between R_2 and W_2:

$$s = -\frac{vr_2}{Z}.$$

Stress at load W_1:

$$\frac{a_1 r_1}{Z}.$$

$$m = \frac{1}{2(l_1 + l_2)}\left(\frac{w_1 a_1 b_1}{l_1}(l_1 + a_1) + \frac{w_2 a_2 b_2}{l_2}(l_2 + a_2)\right).$$



Continuous beam, with two unequal loads at any point of each.

$$\frac{w_1 b_1 - m}{l_1} = r_1 \qquad \frac{w_2 b_2 - m}{l_2} = r_2$$

$$\frac{w_1 a_1 + m}{l_1} + \frac{w_2 a_2 + m}{l_2} = r$$

Stress at support R:

$$\frac{m}{Z}.$$

Stress at load W_2:

$$-\frac{a_2 r_2}{Z}.$$

The greatest of these is the maximum stress.

Between R_1 and W_1:

$$y = \frac{w}{6EI}\left\{(l_1 - w)(l_1 + w)r_1 - \frac{W_1 b_1^3}{l_1}\right\}.$$

Between R and W_1:

$$y = \frac{u}{6EIl_1}[W_1 a_1 b_1 (l_1 + a_1) - W_1 a_1 u^2 - m(2l_1 - u)(l_1 - u)].$$

Between R and W_2:

$$y = \frac{x}{6EIl}[W_2 a_2 b_2 (l_2 + a_2) - W_2 a_2 x^2 - m(2l_2 - x)(l_2 - x)].$$

Between R_2 and W_2:

$$y = \frac{v}{6EI}\left\{[(l_2 - v)(l_2 + v)r_2] - \frac{W_2 b_2^3}{l_2}\right\}.$$

Deflection at load W_1:

$$\frac{a_1 b_1}{6EIl_1}[2a_1 b_1 W_1 - m(l_1 + a_1)].$$

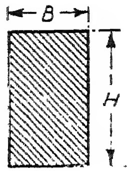
Deflection at load W_2:

$$\frac{a_2 b_2}{6EIl_2}[2a_2 b_2 W_2 - m(l_2 + a_2)].$$

This case is so complicated that convenient general expressions for the maximum deflections cannot be obtained.

VALUES OF I AND Z FOR VARIOUS SECTIONS

(Notes for using Tables on pages 113 to 116)



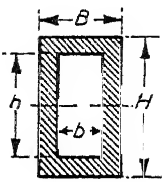
For Rectangular Beams

To find I, given H and B

Find the I given in column 2 opposite the given H for a bar 1 in. wide, and multiply this figure by the given breadth B.

To find Z, given H and B

Find the Z given in column 3 opposite the given H for a bar 1 in. wide and multiply this figure by the given breadth B.



For Hollow Rectangular Beams (thickness of metal at top and bottom being equal)

To find I_h, given H, h, B, and b

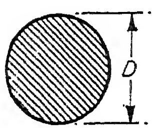
Find the I_o for the outside sizes H and B, as described above.

Find the I_i for the inside sizes *h* and *b*, as described above.

Then $I_h = I_o - I_i$, or the difference of the two.

To find Sh, given H, h, B, and b

First find I*h*, as just described, and divide it by half the height, or $\frac{H}{2}$.

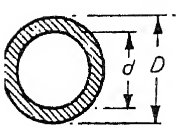


For Circular Beams

The I and Z are given directly in columns 4 and 5.

For Circular Shafts

The I_t and Z_t are given directly in columns 6 and 7.



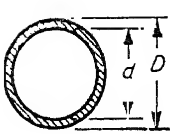
For Hollow Circular Beams (thickness of metal at top and bottom being equal)

To find I_h, given D and d

Find I_o and I_i from the tables, and take the difference, or $I_h = I_o - I_i$.

To find S_h, given D and d

First find I_h as just described, and divide it by half the outside diameter, or $\frac{D}{2}$.



For Hollow Circular Shafts

Proceed exactly as described for hollow circular beams but use columns 6 and 7 instead of columns 4 and 5.

Thus $I_{ht} = I_{ot} - I_{it}$ and $Z_{ht} = I_{ht} \div \frac{D}{2}$.

VALUES OF I AND Z FOR VARIOUS STANDARD SECTIONS

Height or Depth H or Dia. D.	*Bars 1 in. Wide For Bending*		*Circular Sections*			
			For Bending		*For Twisting*	
	$I = \frac{H^3}{12}$	$Z = \frac{H^2}{6}$	$I = \frac{\pi}{64} D^4$	$Z = \frac{\pi}{32} D^3$	$I = \frac{\pi}{32} D^4$	$Z = \frac{\pi}{16} D^3$
$\frac{1}{8}$	0·0001628	0·002604	0·00001198	0·0001917	0·00002397	0·0003835
$\frac{1}{4}$	0·001302	0·01042	0·0001917	0·001534	0·0003835	0·003068
$\frac{3}{8}$	0·004395	0·02344	0·0009707	0·005177	0·001941	0·01035
$\frac{1}{2}$	0·01042	0·04167	0·003068	0·01227	0·006136	0·02454
$\frac{5}{8}$	0·02034	0·06510	0·007490	0·02397	0·01498	0·04794
$\frac{3}{4}$	0·03516	0·09375	0·01553	0·04142	0·03106	0·08284
$\frac{7}{8}$	0·05583	0·1276	0·02877	0·06577	0·05755	0·1315
1	0·08333	0·1667	0·04909	0·09817	0·09817	0·1963
$1\frac{1}{8}$	0·1187	0·2109	0·07863	0·1398	0·1573	0·2796
$1\frac{1}{4}$	0·1628	0·2604	0·1198	0·1917	0·2397	0·3835
$1\frac{3}{8}$	0·2166	0 3151	0·1755	0·2552	0·3509	0·5104
$1\frac{1}{2}$	0·2812	0·3750	0·2485	0·3313	0·4970	0·6627
$1\frac{5}{8}$	0·3576	0·4401	0·3431	0·4213	0·6862	0·8125
$1\frac{3}{4}$	0·4466	0·5104	0·4604	0·5261	0·9208	1·052
$1\frac{7}{8}$	0·5493	0·5859	0·6067	0·6471	1·213	1·294
2	0·6667	0·6667	0·7854	0·7854	1·571	1·571
$2\frac{1}{8}$	0·7996	0·7526	1·001	0·9421	2·002	1·884
$2\frac{1}{4}$	0·9492	0·8437	1·258	1·118	2·516	2·236
$2\frac{3}{8}$	1·116	0 9401	1·562	1·315	3·124	2·630
$2\frac{1}{2}$	1·302	1 042	1·917	1·534	3·835	3·068
$2\frac{5}{8}$	1·507	1·148	2·331	1·776	4·661	3·551
$2\frac{3}{4}$	1·733	1·260	2·807	2·042	5·615	4·083
$2\frac{7}{8}$	1·979	1·378	3·354	2·332	6·707	4·664
3	2·250	1·500	3·976	2·651	7·952	5·301
$3\frac{1}{8}$	2·543	1·628	4·681	2 996	9·363	5·992
$3\frac{1}{4}$	2·861	1·760	5·476	3·370	10·95	6·740
$3\frac{3}{8}$	3·204	1·898	6 369	3·774	12·74	7·548
$3\frac{1}{2}$	3·573	2·042	7·366	4·209	14·73	8·418
$3\frac{5}{8}$	3·969	2·190	8·476	4·676	16·95	9·353
$3\frac{3}{4}$	4·394	2·344	9·707	5·177	19·41	10·35
$3\frac{7}{8}$	4·849	2·503	11·07	5·712	22·14	11·42
4	5·333	2·667	12·57	6·283	25·13	12 57
$4\frac{1}{8}$	5·849	2·836	14·21	6·891	28·42	13·78
$4\frac{1}{4}$	6·397	3·010	16·01	7·536	32·03	15·07
$4\frac{3}{8}$	6·978	3·190	17·98	8·221	35·97	16·44
$4\frac{1}{2}$	7·594	3·375	20·13	8·946	40·26	17·89
$4\frac{5}{8}$	8·244	3·565	22·46	9·713	44 92	19·43
$4\frac{3}{4}$	8·931	3·760	24·99	10 52	49·98	21·04
$4\frac{7}{8}$	9·655	3·961	27·72	11·37	55·45	22 75
5	10·42	4·167	30·68	12·27	61·36	24·54
$5\frac{1}{8}$	11·22	4·378	33·86	13·22	67·73	26·43
$5\frac{1}{4}$	12·06	4·594	37·29	14·21	74·58	28·41
$5\frac{3}{8}$	12·94	4·815	40·97	15·25	81·94	30·49
$5\frac{1}{2}$	13·86	5·042	44·92	16·33	89·84	32·67
$5\frac{5}{8}$	14·83	5·273	49·14	17·47	98·29	34·95
$5\frac{3}{4}$	15·84	5·510	53·66	18·66	107·3	37·33
$5\frac{7}{8}$	16·90	5·753	58·48	19·91	117·0	39·82
6	18·00	6·000	63·62	21·21	127·2	42·41
$6\frac{1}{8}$	19·15	6·253	69·09	22·56	138·2	45·12
$6\frac{1}{4}$	20·35	6·510	74·90	23·97	149·8	47·94
$6\frac{3}{8}$	21·59	6·773	81·08	25·44	162·2	50·87
$6\frac{1}{2}$	22·89	7·042	87·62	26·96	175·2	53·92
$6\frac{5}{8}$	24·23	7·315	94·56	28·55	189·1	57·09
$6\frac{3}{4}$	25·63	7·594	101·9	30·19	203·8	60·39
$6\frac{7}{8}$	27·08	7·878	109·7	31·90	219·3	63·80

Values of I and Z for Various Standard Sections

Height or Depth H. or Dia. D.	Bars 1 in. Wide For Bending		Circular Sections For Bending		Circular Sections For Twisting	
	$I = \frac{H^3}{12}$	$Z = \frac{H^2}{6}$	$I = \frac{\pi}{64} D^4$	$Z = \frac{\pi}{32} D^3$	$I = \frac{\pi}{32} D^4$	$Z = \frac{\pi}{16} D^3$
7	28·58	8·167	117·9	33·67	235·7	67·35
7 1/8	30·14	8·461	126·5	35·51	253·0	71·02
7 1/4	31·76	8·760	135·6	37·41	271·2	74·82
7 3/8	33·43	9·065	145·2	39·38	290·4	78·76
7 1/2	35·16	9·375	155·3	41·42	310·6	82·84
7 5/8	36·94	9·690	165·9	43·52	331·9	87·05
7 3/4	38·79	10·01	177·1	45·70	354·2	91·40
7 7/8	40·70	10·34	188·8	47·95	377·6	95·89
8	42·67	10·67	201·1	50·27	402·1	100·5
8 1/8	44·70	11·00	213·9	52·66	427·9	105·3
8 1/4	46·79	11·34	227·4	55·13	454·8	110·3
8 3/8	48·95	11·69	241·5	57·67	483·0	115·3
8 1/2	51·18	12·04	256·2	60·29	512·5	120·6
8 5/8	53·47	12·40	271·6	62·99	543·3	126·0
8 3/4	55·83	12·76	287·7	65·77	575·5	131·5
8 7/8	58·25	13·13	304·5	68·63	609·1	137·3
9	60·75	13·50	322·1	71·57	644·1	143·1
9 1/8	63·32	13·88	340·3	74·59	680·7	149·2
9 1/4	65·95	14·26	359·4	77·70	718·7	155·4
9 3/8	68·66	14·65	379·2	80·89	758·4	161·8
9 1/2	71·45	15·04	399·8	84·17	799·6	168·3
9 5/8	74·31	15·44	421·3	87·54	842·6	175·1
9 3/4	77·24	15·84	443·6	90·99	887·2	182·0
9 7/8	80·25	16·25	466·8	94·54	933·6	189·1
10	83·33	16·67	490·9	98·17	981·7	196·3
10 1/8	86·50	17·09	515·8	101·9	1,032	203·8
10 1/4	89·74	17·51	541·8	105·7	1,084	211·4
10 3/8	93·06	17·94	568·8	109·6	1,138	219·3
10 1/2	96·47	18·38	596·7	113·6	1,393	227·3
10 5/8	99·96	18·82	625·6	117·8	1,251	235·5
10 3/4	103·5	19·26	655·6	122·0	1,311	243·9
10 7/8	107·2	19·71	686·6	126·3	1,373	252·5
11	110·9	20·17	718·7	130·7	1,437	261·3
11 1/8	114·7	20·63	751·9	135·2	1,504	270·4
11 1/4	118·7	21·09	786·3	139·8	1,573	279·6
11 3/8	122·7	21·57	821·8	144·5	1,644	289·0
11 1/2	126·7	22·04	858·5	149·3	1,717	298·6
11 5/8	130·9	22·52	896·5	154·2	1,793	308·5
11 3/4	135·2	23·01	935·7	159·3	1,871	318·5
11 7/8	139·5	23·50	976·1	164·4	1,952	328·8
12	144·0	24·00	1,018	169·6	2,036	339·3
12 1/4	153·2	25·01	1,105	180·5	2,211	360·9
12 1/2	162·8	26·04	1,198	191·7	2,397	383·5
12 3/4	172·7	27·09	1,297	203·5	2,594	407·0
13	183·1	28·17	1,402	215·7	2,804	431·4
13 1/4	193·9	29·26	1,513	228·4	3,026	456·7
13 1/2	205·0	30·38	1,630	241·5	3,261	483·1
13 3/4	216·6	31·51	1,755	255·2	3,509	510·4
14	228·7	32·67	1,886	269·4	3,771	538·8
14 1/4	241·1	33·84	2,024	284·1	4,048	568·2
14 1/2	254·1	35·04	2,170	299·3	4,340	598·6
14 3/4	267·4	36·26	2,323	315·0	4,647	630·1

Values of I and Z for Various Standard Sections

Height or Depth H. or Dia. D.	Bars 1 in. Wide For Bending		Circular Sections For Bending		Circular Sections For Twisting	
	$I = \frac{H^3}{12}$	$Z = \frac{H^2}{6}$	$I = \frac{\pi}{64} D^4$	$Z = \frac{\pi}{32} D^3$	$I = \frac{\pi}{32} D^4$	$Z = \frac{\pi}{16} D^3$
15	281·2	37·50	2,485	331·3	4,970	662·7
15¼	295·5	38·76	2,655	348·2	5,310	696·4
15½	310·3	40·04	2,833	365·6	5,667	731·2
15¾	325·6	41·34	3,021	383·6	6,041	767·1
16	341·3	42·67	3,217	402·1	6,434	804·2
16¼	357·6	44·01	3,423	421·3	6,846	842·5
16½	374·3	45·38	3,638	441·0	7,277	882·0
16¾	391·6	46·76	3,864	461·4	7,728	922·7
17	409·4	48·17	4,100	482·3	8,200	964·7
17¼	427·7	49·59	4,346	503·9	8,693	1,008
17½	446·6	51·04	4,604	526·2	9,208	1,052
17¾	466·0	52·51	4,873	549·0	9,745	1,098
18	486·0	54·00	5,153	572·6	10,306	1,145
18½	527·6	57·04	5,750	621·6	11,500	1,243
19	571·6	60·17	6,397	673·4	12,794	1,347
19½	617·9	63·38	7,098	728·0	14,195	1,456
20	666·7	66·67	7,854	785·4	15,708	1,571
20½	717·9	70·04	8,669	845·8	17,339	1,692
21	771·8	73·50	9,547	909·2	19,093	1,818
21½	828·2	77·04	10,489	975·7	20,978	1,951
22	887·3	80·67	11,499	1,045	22,998	2,091
22½	949·2	84·38	12,581	1,118	25,161	2,237
23	1,014	88·17	13,737	1,194	27,473	2,389
23½	1,081	92·04	14,971	1,274	29,941	2,548
24	1,152	96·00	16,286	1,357	32,572	2,714
24½	1,226	100·0	17,686	1,444	35,372	2,888
25	1,302	104·2	19,175	1,534	38,350	3,068
25½	1,382	108·4	20,755	1,628	41,511	3,256
26	1,465	112·7	22,432	1,726	44,864	3,451
27	1,640	121·5	26,087	1,932	52,174	3,865
28	1,829	130·7	30,172	2,155	60,344	4,310
29	2,032	140·2	34,719	2,394	69,437	4,789
30	2,250	150·0	39,761	2,651	79,522	5,301

Stress Conversion Table

KILOGRAMMES PER SQUARE MILLIMETRE TO TONS PER SQUARE INCH

Kg. per Sq. mm.	0	1	2	3	4	5	6	7	8	9
	Tons per Square Inch									
0	0·00	0·64	1·27	1·90	2·54	3·17	3·81	4·44	5·08	5·71
10	6·35	6·98	7·62	8·25	8·89	9·52	10·16	10·79	11·43	12·06
20	12·70	13·33	13·97	14·60	15·24	15·87	16·51	17·14	17·78	18·41
30	19·05	19·68	20·32	20·95	21·59	22·22	22·86	23·49	24·13	24·76
40	25·40	26·03	26·67	27·30	27·94	28·57	29·21	29·84	30·48	31·11
50	31·75	32·38	33·02	33·65	34·29	34·92	35·56	36·19	36·83	37·46
60	38·10	38·73	39·37	40·00	40·64	41·27	41·91	42·54	43·18	43·81
70	44·45	45·08	45·72	46·35	46·99	47 62	48·26	48·89	49·53	50·16
80	50·80	51·43	52·07	52·70	53·34	53·97	54·60	55·24	55·88	56·51
90	57·15	57·78	58·42	59·05	59·69	60·33	60·96	61·59	62·23	62·86

Kilogrammes per square millimetre multiplied by 0·635 = Tons per square inch.

Stress Conversion Table

TONS PER SQUARE INCH TO KILOGRAMMES PER SQUARE MILLIMETRE

Tons per Sq. Inch	0	1	2	3	4	5	6	7	8	9
	Kilogrammes per Square Millimetre									
0	0·00	1·57	3·15	4·72	6·30	7·87	9·45	11·02	12·60	14·17
10	15·75	17·32	18·90	20·47	22·05	23·62	25·20	26·77	28·35	29·92
20	31·50	33·07	34·65	36·22	37·80	39·38	40·95	42·52	44·10	45·67
30	47·25	48·82	50·40	51·97	53·55	55·12	56·70	58·27	59·84	61·42
40	63·00	64·57	66·15	67·72	69·30	70·87	72·45	74·02	75·60	77·17
50	78·75	80·32	81·90	83·17	85·05	86·62	88·20	89·77	91·35	92·92
60	94·50	96·07	97·65	99·22	100·80	102·37	103·95	105·52	107·10	108·67
70	110·25	111·82	113·40	114·97	116·55	118·12	119·70	121·27	122·85	124·42
80	126·00	127·57	129·14	130·72	132·30	133·87	135·45	137·02	138·59	140·15
90	141·75	143·32	144·90	146·47	148·05	149·62	151·20	152·77	154·35	155·92

Tons per square inch multiplied by 1·575 = Kilogrammes per square millimetre.

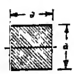
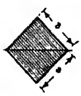
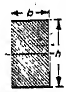
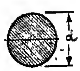
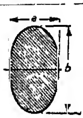
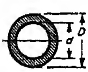
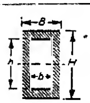
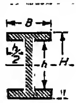
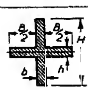
Chords and Radians

Degs.	*Chords*	*Differences for 10′*	*Radians*	*Constant Differences* min. sec.	*Degs.*	*Chords*	*Differences for 10′*	*Radians*	*Constant Differences* min. sec.
0	0·0000	29	0·0000	1 3					
1	0·0175	29	0·0175	2 6	46	0·7815	27	0·8029	2 6
2	0·0349	29	0·0349	3 9	47	0·7975	27	0·8203	3 9
3	0·0524	29	0·0524	4 12	48	0·8135	27	0·8378	4 12
4	0·0698	29	0·0698	5 15	49	0·8294	26	0·8552	5 15
5	0·0872	29	0·0873	6 17	50	0·8452	26	0·8727	6 17
6	0·1047	29	0·1047	7 20	51	0·8610	26	0·8901	7 20
7	0·1221	29	0·1222	8 23	52	0·8767	26	0·9076	8 23
8	0·1395	29	0·1396	9 26	53	0·8924	26	0·9250	9 26
9	0·1569	29	0·1571	10 29	54	0·9080	26	0·9425	10 29
10	0·1743	29	0·1745	—	55	0·9235	26	0·9599	—
11	0·1917	29	0·1920		56	0·9389	26	0·9774	
12	0·2091	29	0·2094		57	0·9543	26	0·9948	
13	0·2261	29	0·2269		58	0·9696	25	1·0123	
14	0·2437	29	0·2443		59	0·9848	25	1·0297	
15	0·2611	29	0·2618		60	1·0000	25	1·0472	
16	0·2783	29	0·2793		61	1·0151	25	1·0647	
17	0·2956	29	0·2967		62	1·0301	25	1·0821	
18	0·3129	29	0·3142		63	1·0450	25	1·0996	
19	0·3301	29	0·3316		64	1·0593	25	1·1170	
20	0·3473	29	0·3491		65	1·0746	24	1·1345	
21	0·3645	29	0·3665		66	1·0893	24	1·1519	
22	0·3816	29	0·3840		67	1·1039	24	1·1694	
23	0·3987	28	0·4014		68	1·1184	24	1·1868	
24	0·4153	28	0·4189		69	1·1328	24	1·2043	
25	0·4329	28	0·4363		70	1·1472	24	1·2217	
26	0·4499	28	0·4538		71	1·1614	24	1·2392	
27	0·4669	28	0·4712		72	1·1756	23	1·2566	
28	0·4838	28	0·4887		73	1·1896	23	1·2741	
29	0·5008	28	0·5061		74	1·2036	23	1·2915	
30	0·5176	28	0·5236		75	1·2175	23	1·3090	
31	0·5345	28	0·5411		76	1·2313	23	1·3265	
32	0·5513	28	0·5585		77	1·2450	23	1·3439	
33	0·5680	28	0·5760		78	1·2586	23	1·3614	
34	0·5847	28	0·5934		79	1·2722	22	1·3788	
35	0·6014	28	0·6109		80	1·2856	22	1·3963	
36	0·6180	28	0·6283		81	1·2989	22	1·4137	
37	0·6346	28	0·6458		82	1·3121	22	1·4312	
38	0·6511	27	0·6632		83	1·3252	22	1·4486	
39	0·6676	27	0·6807		84	1·3383	22	1·4661	
40	0·6840	27	0·6981		85	1·3512	21	1·4835	
41	0·7004	27	0·7156		86	1·3640	21	1·5010	
42	0·7167	27	0·7330		87	1·3767	21	1·5184	
43	0·7330	27	0·7505		88	1·3893	21	1·5359	
44	0·7492	27	0·7679		89	1·4018	21	1·5533	
45	0·7654	27	0·7854		90	1·4142	—	1·5708	

A. 1 right angle = $\frac{\pi}{2}$ radians = 1·5707963 radians.
log. 1·57078 = ·1961.
1 radian = 57·2958° = 57° 17′ 45″.
log. 57·2958 = 1·7581.
To convert radians into seconds multiply by 206265.
log. 206265 = 5·3144.

B. Chord = diameter × sine of angle subtended at circumference.
= diameter × sine of semi-angle subtended at centre.

Moduli of Sections and Moments of Inertia

Section	*Area*	*Modulus of the Section* $\frac{I}{\text{half depth}}$	*Moment of Inertia I about the Axis shown in first column*
	a^2	$\frac{a^3}{6}$	$\frac{a^4}{12}$
	a^2	$\frac{a^3\sqrt{2}}{12}$	$\frac{a^4}{12}$
	$b\,h$	$\frac{b\,h^2}{6}$	$\frac{b\,h^3}{12}$
	$\frac{\pi\,d^2}{4}$	$\frac{\pi\,d^3}{32}$	$\frac{\pi\,d^4}{64}$
	$\frac{\pi\,a\,b}{4}$	$\frac{\pi\,a\,b^2}{32}$	$\frac{\pi\,a\,b^3}{64}$
	$\frac{\pi}{4}(D^2-d^2)$	$\frac{\pi}{32}\,\frac{(D^4-d^4)}{D}$	$\frac{\pi}{64}(D^4-d^4)$
	$B\,H-b\,h$	$\frac{B\,H^3-b\,h^3}{6H}$	$\frac{B\,H^3-b\,h^3}{12}$
	$B\,H-b\,h$	$\frac{B\,H^3-b\,h^3}{6H}$	$\frac{B\,H^3-b\,h^3}{12}$
	$b\,H+B\,h$	$\frac{b\,H^3+B\,h^3}{6H}$	$\frac{b\,H^3+B\,h^3}{12}$

THE MICROMETER

Reading a Micrometer.—On a micrometer reading in inches the spindle is threaded 40 threads per inch. The line along the barrel is engraved, so that when the micrometer is held as shown in Fig. 1, it is in the direct vision of the operator. This line is, along its lower edge, divided into forty parts, every fourth line commencing from the frame being marked with a numeral from 1 to 10. The end of the thimble is graduated into twenty-five equal parts. When the gauging faces are touching, one of these lines exactly coincides with the long line on the barrel, and the feather edge of the thimble is in line with the first vertical line. This line on the thimble is marked 0, and every fifth line is marked with a number, thus, 5, 10, 15, 20. This means that the divisions along the barrel represent

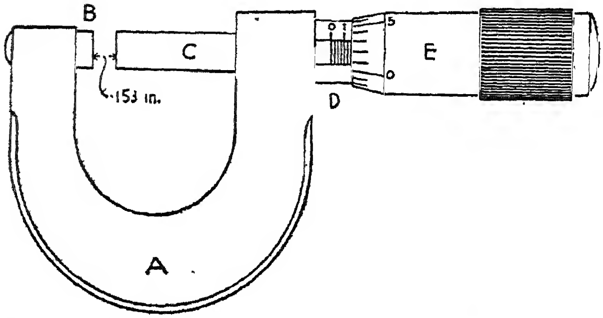


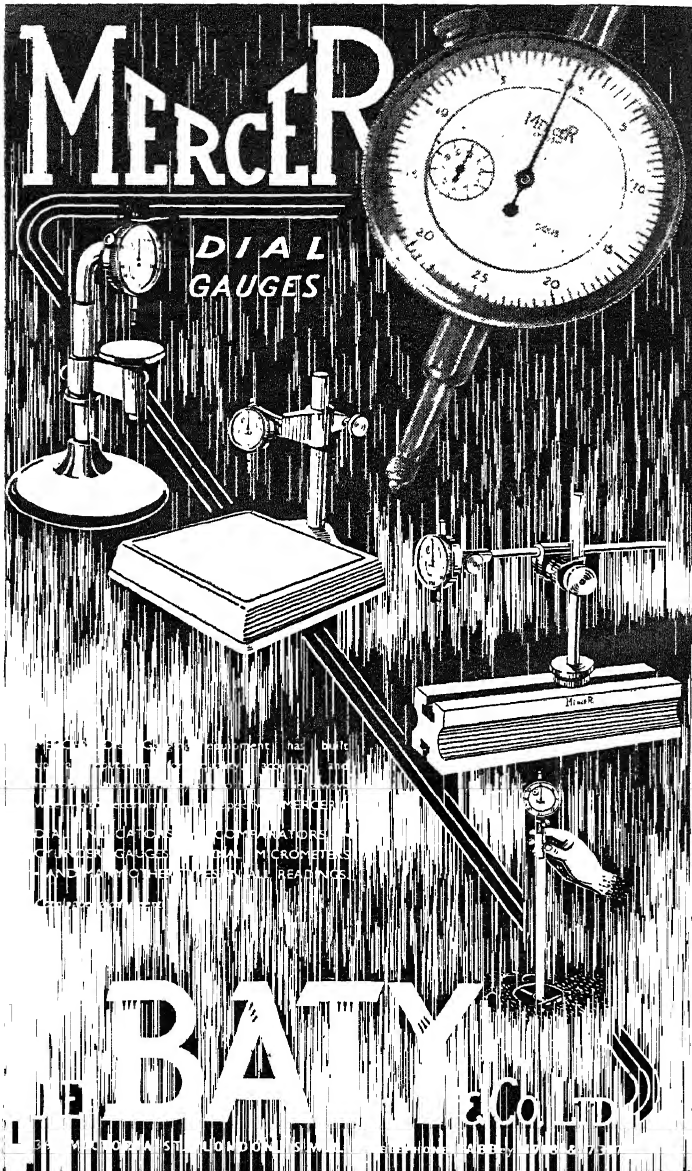
Fig. 1.—The micrometer and its parts. A is the frame, B the hardened steel anvil, C the spindle, D the graduated sleeve and E the graduated thimble attached to the spindle. The reading is 0·153 in.

fortieths of an inch, and the distance between the numbered lines four fortieths, or 1/10 in. The divisions on the thimble, then, represent one twenty-fifth of one fortieth, or 1/1000 in. It will be seen that the reading is in decimal fractions. Thus ½ in. becomes 0·5 in., and to set the micrometer to this size, the thimble is unscrewed until the zero mark on it corresponds to the line marked 5 on the barrel, that is 5/10 in. To give another example of setting we will take the decimal equivalent of 3/16 in., which is 0·1875 in., or one tenth, eight hundredths, and seven and a half thousandths. Set the zero mark on the thimble to number 1 on the barrel; three further complete turns to the spindle adds seventy-five thousandths; this leaves twelve and a half thousandths, or twelve and a half divisions on the thimble to be added.

Some 1-in. micrometers have the decimal equivalent of from 1/64 in. to 63/64 in. in sixty-fourths engraved on the frame, which is a very convenient arrangement.

Micrometer Vernier Scale.—Micrometers reading in tenths of thousandths are obtainable. These are read in the ordinary way to three places of decimals, but the fourth place is read on a vernier (Fig. 2). Above the datum line on the barrel is another line parallel to it. This line corresponds to the fifth line on the thimble, with the zero mark set at the datum line. At a distance away from the second line equal to nine divisions on the thimble is another line, the space between these lines being divided into ten equal parts. The number of tenths of thousandths are added as follows: assume it is necessary to add 4; take the line marked 4 on


M&W MICROMETERS
MEMBERS OF THE BRITISH STANDARDS INSTITUTION
MEMBERS OF THE GAUGE & TOOL MAKERS ASSOCIATION
MOORE & WRIGHT SHEFFIELD ENGLAND
A Complete Range made to conform to British Standard Institution Specifications Nos 870 & 950
ACCURATE
STURDY &
DEPENDABLE
MOORE & WRIGHT (SHEFFIELD) LTD
SHEFFIELD
ENGLAND


MERCER
DIAL GAUGES
BATY & CO. LTD

the vernier and bring alongside the line on the thimble that is nearest, keeping the thimble moving in a direction to unscrew the spindle.

Metric Micrometer.—The metric micrometer has a screw with a pitch of ½ mm. The distance traversed by the screw during one complete revolution is ½ mm. (0·50 mm.), and two complete revolutions move the screw a distance of 1·00 mm. The graduations on the barrel conform to the pitch of the screw. The upper set of graduations representing mm. is numbered every fifth graduation; the lower set of graduations subdivides each mm. division into two equal parts. The bevelled edge of the thimble is graduated into 50 parts, and figured every fifth division—0, 5, 10, 15, 20, 25, 30, etc. When 50 of these graduations have passed the horizontal line on the barrel, the spindle, having made one revolution, has moved 0·50 mm. Thus, when the spindle only moves far enough

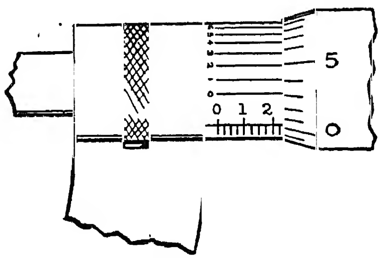


Fig. 2.—The micrometer vernier scale.

to cause one graduation to pass the horizontal line on the barrel it will have moved 1/50th of 0·50 mm. or 0·01 mm. The distance between the graduations on the thimble is great enough to permit half and quarter hundredths of a mm. to be readily estimated.

To read.—First note the last figure visible on the scale on the barrel representing a whole mm. Note whether or not a half mm. division is visible beyond this graduation. Then determine the hundredths mm. by the line on the thimble coinciding with the horizontal line on the barrel. The mm. shown (plus 0·50 mm. if a half mm. graduation shows), plus the number of hundredths of a mm., is the reading.

The reading is taken in the same manner as with English measure.

THE VERNIER

The modern vernier caliper consists as shown in Fig. 3 of a stock or beam upon which is inscribed a scale known as the " true scale "; the end of the beam being shaped to form the fixed jaw of the caliper whilst over the beam or stock is fitted a sliding saddle carrying a vernier scale and acting as the sliding jaw of the caliper. An anchor slide having a fine adjustment nut is attached by means of a fine threaded stud to the sliding saddle.

Vernier calipers can be obtained in English or metric measure and on those used for reading in English measurements, the " true scale " inscribed on the beam is usually graduated in inches, being numbered consecutively 1, 2, 3, 4, 5, etc., each inch being divided into ten equal parts (0·100) and each tenth part subdivided into four spaces equal to $\frac{0{\cdot}100}{4}$ or 0·025 in., thus making a total of forty equal divisions in each inch. Verniers may also be obtained with graduations such as fiftieths or 0·020 of an inch, in which case the vernier scale would have 20 divisions over a distance of 19 spaces on the true scale.

The vernier scale carried on the saddle of the sliding jaw is graduated into twenty-five equal parts which are numbered at every fifth division, thus, 5, 10, 15, 20, and 25; these divisions on the vernier scale correspond in extreme length with twenty-four parts on the "true scale," or 24 × 0·025 in. = 0·600 in., therefore one division on the vernier being 0·600 divided by 25 = 0·024 in.; thus the difference

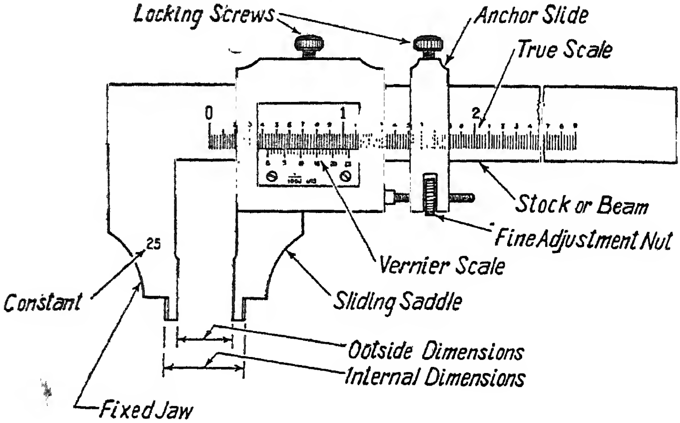


Fig. 3.—The vernier caliper.

between a division on a vernier scale and a division on the "true scale" equals 0·025 minus 0·024 = 0·001 in., or in other words, one thousandth part of an inch.

If the sliding jaw carrying the vernier scale is moved along the beam of the instrument so that the graduation marked "0" on the vernier scale corresponds exactly with any one graduation mark on the "true scale," then the two adjacent graduations on the right-hand sides of the scales will differ from each other to the extent of one thousandth part of an inch and the difference will continue to increase at the rate of one thousandth part of an inch for each division until they correspond again at the line marked 25 on the vernier scale.

To read the distance between the measuring faces of the vernier caliper, commence by noticing how many inches, tenths, or parts of tenths that the zero of the vernier scale points to on the "true scale"; then count the number of divisions on the vernier scale until one is found that coincides with an opposite one on the "true scale," as this point will indicate the number of thousandths of an inch that has to be added to the distance measured on the "true scale."

Example: Fig. 4 depicts a portion of the "true scale" and also the vernier scale of a typical vernier caliper graduated in English measure in fortieths or 0·025 of an inch.

The upper portion of the illustration marked *A* shows the zero graduation of the vernier scale corresponding exactly with a fortieth graduation on the "true scale"; this point is at the second fortieth mark to the extreme right of 2·3 in., thus the reading of the vernier caliper in this instance is 2·000 plus 0·300 plus 0·050 = 2·350 in. The lower portion of the illustration marked *B* shows the vernier scale altered so that it coincides exactly at the eighteenth mark on the vernier scale exactly with a line on the "true scale"; this indicates that 0·018 shown on the vernier scale must be added to the reading shown on the "true scale," thus the final reading of the vernier indicating the distance between the measuring faces in this instance would be 2·000 plus 0·300 plus 0·050 plus 0·018 = 2·368 in.

Metric Readings.—On the vernier caliper arranged for metric measurements the "true scale" is usually graduated into ½ mm., or 0·50 mm., and the vernier

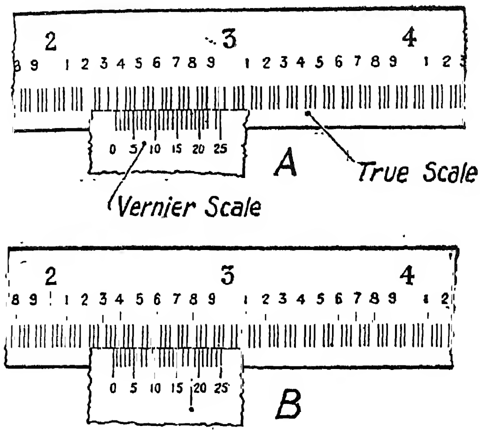


Fig. 4.—Portion of true scale and vernier scale of vernier caliper.

scale is made with 25 divisions numbered every fifth division; the extreme length of the vernier scale in this instance is equal to 24 divisions on the "true scale"

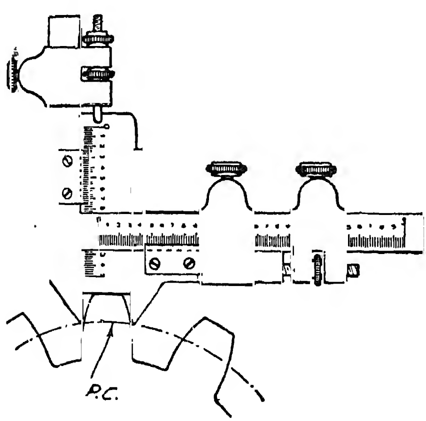


Fig. 5.—The gear-tooth vernier. This consists of the usual vernier slide plus a vernier depth gauge, so that the chordal thickness of the gear teeth can be measured.

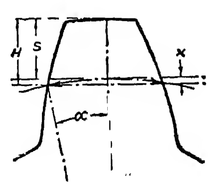


Fig. 6.—Chordal height on pitch line of gear.

or 24 × 0·50 mm. = 12 mm., thus each division on the vernier scale is equal to 1/25 of 12 mm. = 0·48 mm.

The difference, therefore, between a division on the "true scale" on the beam of the instrument and a division on the vernier scale is equal to 0·50 mm., minus 0·48 mm. = 0·02 mm., or 1/50 mm., the usual accuracy to which metric verniers read.

When taking internal measurements with a vernier caliper that does not permit direct reading, allowance must be made for the combined width of the caliper nibs; this allowance is usually marked by the maker on the fixed jaw of the caliper.

To set the vernier accurately, the locking screw on the sliding saddle and anchor slide should be slackened and the sliding saddle moved so that the fixed jaw and sliding jaws of the caliper are lightly contacting the surfaces being measured; when this approximate setting has been made, the anchor slide should be locked firmly in position on the beam so that, by manipulation of the fine adjustment nut, the sliding saddle can be manipulated to the exact setting and locked in position by the appropriate locking screw.

In measuring the thickness of gear teeth on the pitch line, it is necessary to add the chordal height X (Fig. 6) to the addendum S, and a gear-tooth vernier (Fig. 5) is used for this purpose. The vernier is thus set to height H in order to measure tooth thickness on the pitch line.

$X = R\,(1 - \cos a)$

where R = pitch radius

$a = 90° \div N$

N = number of teeth in the gear.

Chordal thickness $= 2R \sin a$

where $a = \frac{1}{2}$ angle subtended from centre of gear

or Pitch diameter $\times \sin\left(\frac{90°}{\text{No. of teeth}}\right)$.

UNIVERSAL PROTRACTOR

The disc of the universal protractor (Fig. 7) is graduated in degrees from 0 to 90 each way. The vernier plate is graduated so that the 12 divisions on the vernier occupy the same space as 23 divisions on the disc. The difference between the

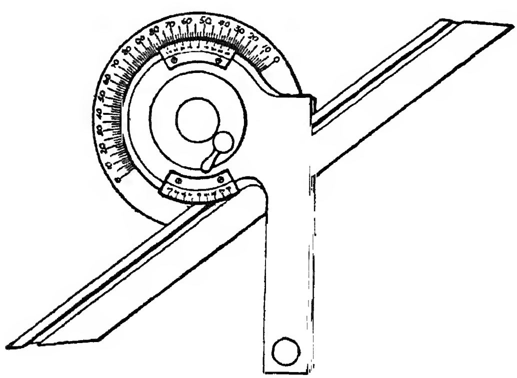


Fig. 7.—Universal protractor.

width of one of the 12 spaces on the vernier and two of the 23 spaces on the disc is therefore 1/12 of a space on the disc. Each space on the vernier is 1/12 of a degree, or five minutes shorter than two spaces on the disc. If a line on the vernier coincides with a line on the disc and the protractor is rotated until the next

line on the vernier coincides with the next line on the disc, the vernier has been moved through an arc of 1/12 of a degree, or 5′.

Reading.—To read the protractor, note on the disc the number of whole degrees between 0 on the disc and 0 on the vernier. Then count in the same direction the number of spaces from 0 on the vernier to a line that coincides with

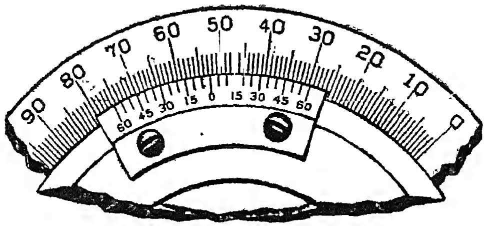


Fig. 8.—Enlarged view of vernier scale of universal protractor.

a line on the disc. Multiply this number by 5 and the product will be the number of minutes to be added to the number of whole degrees.

In Fig. 8 the number of degrees between 0 on the disc and 0 on the vernier is 52. The line marked 45 on the vernier coincides with a line (70) on the disc, the number of spaces from 0 being 9. Multiplying this number by 5 gives 45, the number of minutes to be added to the number of degrees. The reading of the protractor is 52 degrees 45 minutes (52° 45′).

THE SINE BAR

The sine bar enables the value of an angle to be determined with a greater degree of accuracy than is possible with the vernier protractor. It is, of course, used in conjunction with tables of sines, and for setting purposes a height gauge and slips are necessary.

Standard sine bars are made in two lengths, 10 in. and 5 in., and the equivalent measurement to bring a bar up to the angle required is found by multiplying the sine

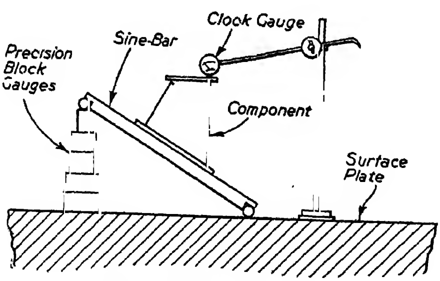


Fig. 9.—The sine bar in use.

of the angle by the length of the sine bar being used. For example, if it is required to set a 5-in. sine bar at 5°, the sine of this will be found from the tables to be 0·08715, and multiplying this by five 0·43575 is obtained.

If a 10-in. sine bar is used, then the value would be 0·8715. A 10-in. bar is preferable as it is merely necessary to move the decimal point one place to the right in order to obtain the required value. Fig. 9 shows a sine bar in use. The

distance H (Fig. 10) is the measurement between the centres of the rollers of the sine bar. One roller is placed on the surface plate, and the other on the top of a pile of slips or gauge blocks, to height O.

When using the double sine table with 10-in. and 5-in. sine bar centres on special compound angles, it is necessary to calculate the corrected angle. If

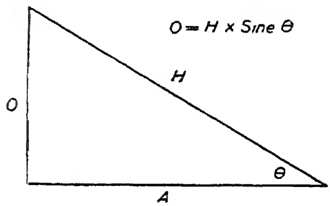


Fig. 10.—The sine bar is set to height O, found by multiplying the length of the sine bar by the sine of the angle.

angle A is the angle set by the lower sine bar, and angle B the angle set by the upper sine bar, the two angles between the upper surface is angle C; then:

$$\cos C = \cos A \cos V$$

thus in the case of the 10-in. bar being set at 25° and the 5-in. bar at 45° C would equal:

$$\begin{aligned} \cos C &= \cos 25° \cos 45° \\ &= 0{\cdot}9063 \times 0{\cdot}7071 \\ &= 0{\cdot}461 \\ \text{whence } C &= 50° \, 8'. \end{aligned}$$

The Comparator.—Slip gauges are in universal use in the majority of tool-rooms, not only for setting up a sine bar, but also in cases where very fine measurements are necessary; for instance, if a pin projected from a jig or fixture that had to be 2·5005 in. from the base, the usual method of checking this dimension would be on the surface plate with the use of the dial indicator set to the necessary amount of slip gauges and adjusted to zero, and then the point of the indicator passed over the projecting pin in question (Fig. 9).

Very similar to this is the practice of setting up a comparator—a method by which a group of articles is measured with extreme delicacy. This is an instrument with a permanent dial gauge which is adjusted to the required dimension with the aid of slip gauges, usually back to zero. The article requiring to be measured is then passed under the indicator as a comparison to the gauges to which the instrument was previously set. It will be seen from this that a group of articles can be infallibly checked with great rapidity.

The following table is used in the U.S.A. to indicate surface standards for surface finish.

Symbol Used	*Root Mean Square Height of Irregularities*	
	Micro-in.	*In.*
63M	63,000	0·063
16M	16,000	0·016
4M	4,000	0·004
1M	1,000	0·001
250	250	0·00025
63	63	0·000063
32	32	0·000032
16	16	0·000016
8	8	0·000008
4	4	0·000004
2	2	0·000002
½	½	0·0000005
¼	¼	0·00000025

Style of Drawings.—No embellishments are allowed on drawings, but these are retained as plain and prosaic as possible. Shading is not allowed on engineering drawings except in a few offices. All corners must be neatly executed. Centre lines are always shown for holes and other round depressions or protrusions, even if not required for dimensional purposes.

No freehand work is allowed even for very small radii ; all lines must be executed with square or compass. Printing alone may be freehand, and this is usually insisted upon. Stencils may be used for large printing, e.g. drawing serial numbers and title.

Orthographic projection of the first angle form is generally used in this country, whilst the third angle form is used in the U.S.A. (See " Projections.") Pictorial views, both of the assembled and exploded types, are increasing in use, particularly in the aircraft industry.

The outline of the component should be drawn in thick, bold lines, with projection and dimension lines thin. This method centres attention on the profile of the component, and renders this against a background of dimensions, notes, and arrows.

Drawings are usually rectangular in shape and arranged to read from the long side of the rectangle. The drawing serial number is often repeated in each corner on large sheets so as to read from off the sheet as shown in Fig. 1.

For the one off job, drawings may be executed in pencil with ink arrowheads, dimensions, notes, title, and drawing number if a translucent detail-tracing paper is used. Reproduction prints may be made from such drawings if pencil lines are boldly executed, using pencil of F, H, or 2H grade. A more lasting and higher-class job is achieved by using pencil cloth and fixing with recommended solution.

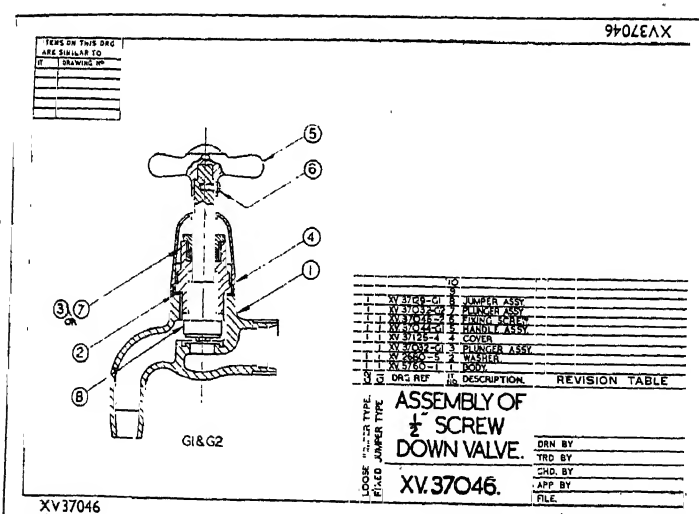


Fig. 1.—Arrangement of drawing

Lettering.—Two styles of lettering are used in line with specimen shown in Fig. 2. The second style (small letters) is only used where the drawing size necessitates such small characters that the block style, first shown, would become illegible.

All printing must be maintained strictly upright for most drawing offices. No

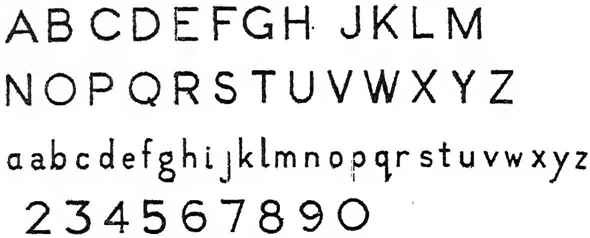
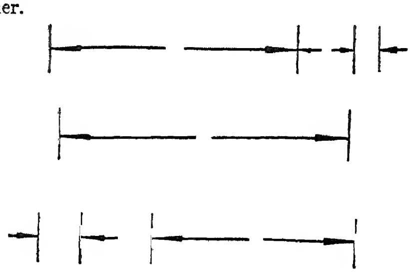


Fig. 2.—Usual style of lettering.

slope forward or back is allowed, since this would vary from one draughtsman to another. Opinions differ on this point. Some offices prefer sloping printing of the forward type, whilst others insist on vertical form only. The British Standard Specification 308 (1943), however, recommends sloping letters and figures for general use, but vertical characters for drawing numbers, titles, and reference numbers.

Note the position (Fig. 2) of horizontal lines in characters—where character is square, e.g. E, H, etc., middle horizontal line bisects height; where character is tapered, e.g. A, mid-horizontal point is displaced from centre.

Characters in words are spaced as close together as possible for legible results. This allows a closer word spacing. Legibility of prints depends upon the size of gaps in characters, as all lines bleed slightly on exposure and development. Straight sections of characters are maintained straight and not curved in any manner.



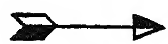


Fig. 4.

Fig 3

Fig. 5.

Figs. 3 to 5.—Dimension lines.

Small lettering must maintain all tails straight, vertical, and of uniform length if neat results are to be achieved. A mapping pen is generally used and the style confined to customers' drawings, such as outlines and specification sheets.

Execution of Printing.—The aim of the printer is to produce characters of regular formation, of uniform size, and of such style that each is instantly recognised from all others. Neatness and legibility are also ruling factors

Where neatness is important, printing is executed between two pencil guide lines lightly drawn on the paper with a third line as datum for mid-horizontals. To increase working speed these lines may be drawn on a separate sheet of suitable size for slipping between tracing and original, thereby effecting quick set up by means of tee square.

Either the conventional writing pen or ruling pen may be used for printing. The former gives more characteristic results, whilst the latter permits of higher working speed since a larger reservoir of ink is held by the ruling pen.

When tabulating, words which repeat one above the other should have each respective character and letter spaced in strictly vertical lines. The homogeneous result thus obtained enhances the appearance of the drawing.

Arrows.—These should be long and slender. Large blobs of ink spoil the appearance of the drawing. In most cases a mere slight thickening of the line will give all indication necessary. The length of the arrowhead is made proportional to the length of the line bearing it. A variety of arrowhead proportions for dimensional location are shown in Fig. 3. Examples are included where dimensions are co-linear at one point.

In the case of arrows pointing to a group of holes, one arrow only is used. The direction of the arrow is such that, if produced, the point would pass through the

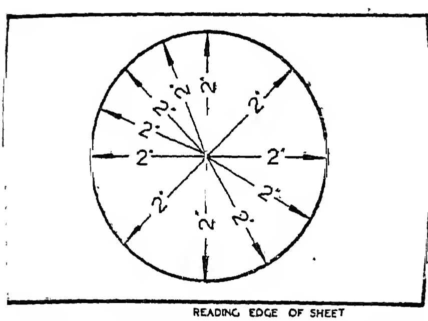


Fig. 6.—Intermediate angular positions of dimensions.

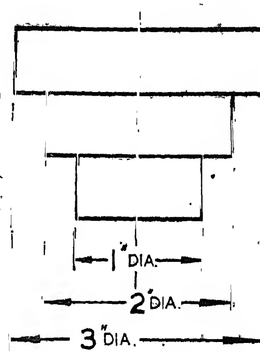


Fig. 7.—Staggered dimensions.

centre of the hole. The tail of the arrow need not be unidirectional, but may be bent to follow most advantageous route to nearest open space. The straight portion nearest the head of the arrow should always be short in comparison with the true tail. Arrow tails are not allowed to cross, since the result is ambiguous unless jumpers are used with consequent untidiness.

Where arrows are used for purely indication purposes, e.g. the direction of a view, a distinctive form may be used in line with that shown in Fig. 4.

Dimensions.—The axis of the dimension is made parallel to the line of the arrows indicating its bounds, as shown in Fig. 5. A gap is arranged to accommodate the dimension, which is so positioned that the arrow line bisects the height of the figures. The dimension is written to read from the reading edge of the drawing sheet or from the right-hand side. For intermediate angular positions see Fig. 6. Where dimensions tend to become crowded, these may be staggered as in Fig. 7.

Where dimensions are quoted as vulgar fractions, the line dividing numerator and denominator (solidus) is drawn horizontal. Any deviation from this rule is liable to cause error in reading the dimension.

For decimal dimensions B.S.S. 308 stipulates that: "Where the dimension is less than unity the cipher (0) preceding the decimal point should be omitted on production drawings." Actually it is usual to omit the cipher "0" for dimensions less than unity, except in the case of notes where no indication of the position of the decimal point is given. On the drawing, the general proportions of scale show this.

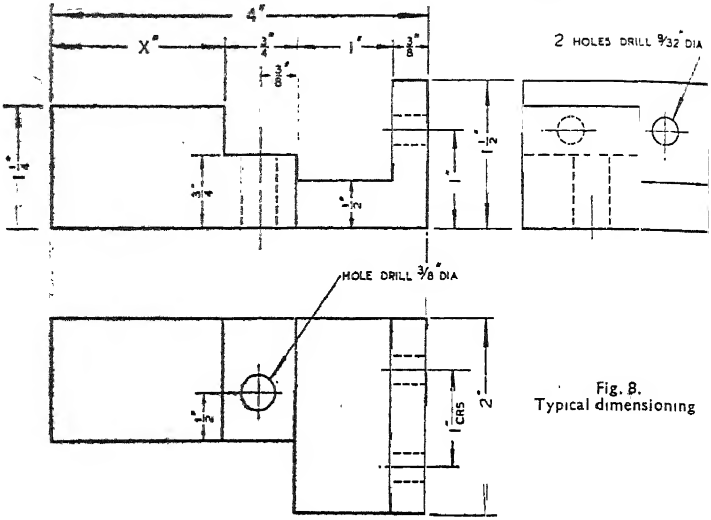


Fig. 8.
Typical dimensioning

All contours of a component must be completely dimensioned, i.e. it must be possible to manufacture entirely from dimensions, for scaling off the drawing is not permitted.

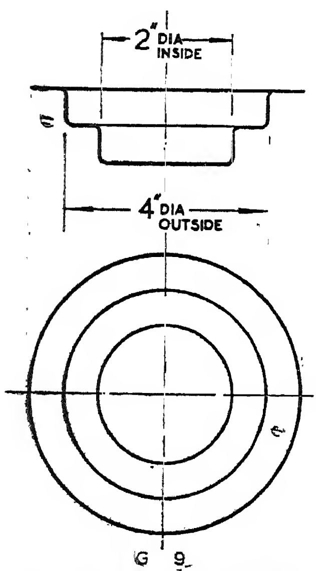


Fig. 9.—Inside and outside dimensions.

Dimensions relative to a given contour are maintained as near one another as possible. If holes are located in one view, then drilling instructions are also logged in that view. This expedites reading of the drawing. Where all dimensions of a contour cannot be logged in one view, it is preferred that one dimension shall not be quoted alone in a remote view unless conspicuously on its own. It is sometimes better to transfer a few dimensions with that which must appear in the other view. See Fig. 8, where drilling instructions for the two holes $\frac{9}{32}$ in. diameter appear alone in the side elevation and the dimension of $\frac{1}{2}$ in. accompanies the specification of the $\frac{3}{8}$ in. diameter hole in the plan view.

Double Dimensions.—This is recognised as repeating information, either in the same manner or in different ways. If in Fig. 8 the missing dimension marked "X" ($2\frac{1}{8}$ in.) had been quoted this would have repeated the 4 in. overall dimension above $\frac{3}{4}$ in., 1 in., and $\frac{3}{8}$ in. Such practice is avoided as far as possible in the drawing office, and is only tolerated for such cases as multi-stepped shafts, where the calculation of the omitted dimension may require careful evaluation by the operator. Further, by omitting the least important dimension indication is given as to which

are the more important contours and so the method of dimensioning may be taken as instructions for "marking off" procedure.

Another reason for omitting double dimensions is that one or other of these may be overlooked should a change be made to the drawing.

Abbreviations Used with Dimensions.—The following abbreviations are generally recognised:

"CRS."—Centres

When holes are required equally spaced on a centre line for matching purposes, the letters "CRS." are added after the dimension of overall distance between the holes.

"DIA."—Diameter

This is only quoted where a complete circle is in evidence. Radius is quoted otherwise.

Where thin sheet-metal work is the subject, a single line may be used to denote thickness, but dimensions must indicate whether size quoted is inside or outside as follows: "X" DIA. (INSIDE), "Y" DIA. (OUTSIDE). (See Fig. 9.)

"R."—Radius

The letter "R" placed after a dimension indicates that the contour follows the

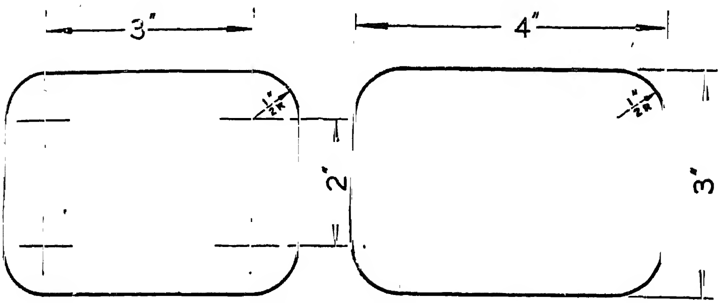


Fig. 10.—Radius indication.

arc of a circle about a centre which must be directly or indirectly located. (See Fig. 10.)

"P.C.D."—Pitch Circle Diameter

Where holes are to be located on the periphery of a circle, the letters P.C.D. are added after the dimension of circle diameter, e.g. six holes ⅜ in. DIA. equally spaced on 5 in. P.C.D. are shown in Fig. 11.

"N.T.S."—Not to Scale

Where a dimension is not of correct length according to the scale used, the letters "N.T.S." indicate this. The abbreviation is usually employed where to bring the dimension to scale would necessitate complete redraughting or where a late design change has been notified. Most offices allow the underlining of the dimension concerned to indicate this condition.

Special Dimensions.—It is sometimes of advantage to sidetrack rules of the office system. This is allowed provided it is made clear that a rule has been evaded and if it is of advantage to do so.

Although no other than purely assembly dimensions may appear on an assembly drawing, dimensions quoting important *calculated* clearances, aggregate distances, etc., may be logged if the note "D.O.REF." is added after the dimension concerned. This shows that it is purely a theoretical dimension and is not to be considered in production.

Similarly, references may be made to related apparatus providing the "D.O.REF." note is included.

Notes.—These are made terse and the imperative tense is always used. Past participles are avoided to render the note as an instruction to the worker rather than a description of what *has* been done.

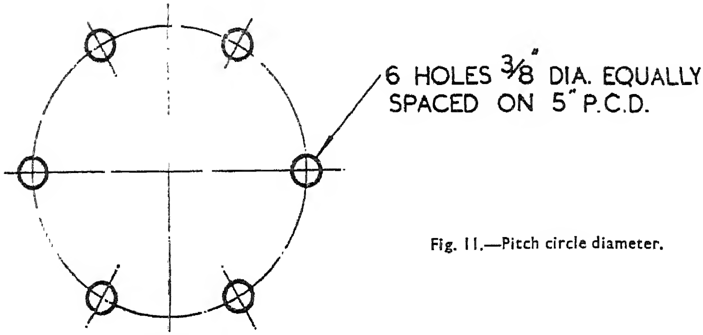


Fig. 11.—Pitch circle diameter.

Grouping of information in notes is of importance to avoid reading errors. Numerical information is separated by written words and as much assistance as possible given to the operator. Where gauge sizes are quoted, equivalent sizes are also recorded, both as a convenience to the operator and as a check for the draughtsman.

Standard forms of notes for drawings appear in Fig. 12.

HOLES

Drilling :
Hole drill $\frac{3}{16}''$ dia.
2 holes drill $\frac{3}{16}''$ dia.

Counter Boring and Counter Sinking :
Hole $\frac{7}{16}''$ dia. C'bore $\frac{1}{2}''$ dia. × $\frac{1}{16}''$ deep.
Hole $\frac{5}{16}''$ dia. C'sk $\frac{1}{2}''$ dia.

Tapping :
Hole tap 2BA.
Hole tap 2BA × $\frac{1}{4}''$ deep.
Drill $\frac{3}{8}''$ deep.

Standard Drill Sizes :
Hole No. 2 drill (0·221" dia.).
Hole letter G drill (0·261" dia.).

Reamering :
Hole drill $\frac{23}{64}''$ dia.
Ream $\frac{3}{8}''$ dia.

Cast Holes :
Hole $2\frac{1}{2}''$ dia. Core $2\frac{1}{4}''$ dia.
3 holes $\frac{3}{8}''$ dia. Spotted on casting.

Special Location :
Hole drill $\frac{5}{16}''$ dia.
Locate on assembly.

GENERAL MACHINING

Machined Surfaces :
Cross-hatched lines show machined surface
or
f General machined finish.
rf Rough machined.
ff Fine machined finish.
sf Smooth finish.
(Letters written on line to be processed).

Threading :
Screw $\frac{3}{8}''$ Whit.
Tap $\frac{3}{8}''$ B.S.P.T.

Chamfer :
$\frac{1}{16}''$ cham. at 45°.
Chamfer to give lead.

Undercuts :
Screw 2" B.S.P.T. Undercut $\frac{1}{16}''$ to bottom of thread.

Special Indent Finishes :
Serrate. Knurl. With arrow to surface to be treated and corner hatched to show finish.

Spot Facing :
4 holes $\frac{1}{2}''$ dia. Spot face 1" dia.

GENERAL INSTRUCTIONS

Reading Guides :
Section on AA.
Part section on AA.
View in direction of arrow "X."
All other particulars as item "X."
As item "X" but opposite hand.

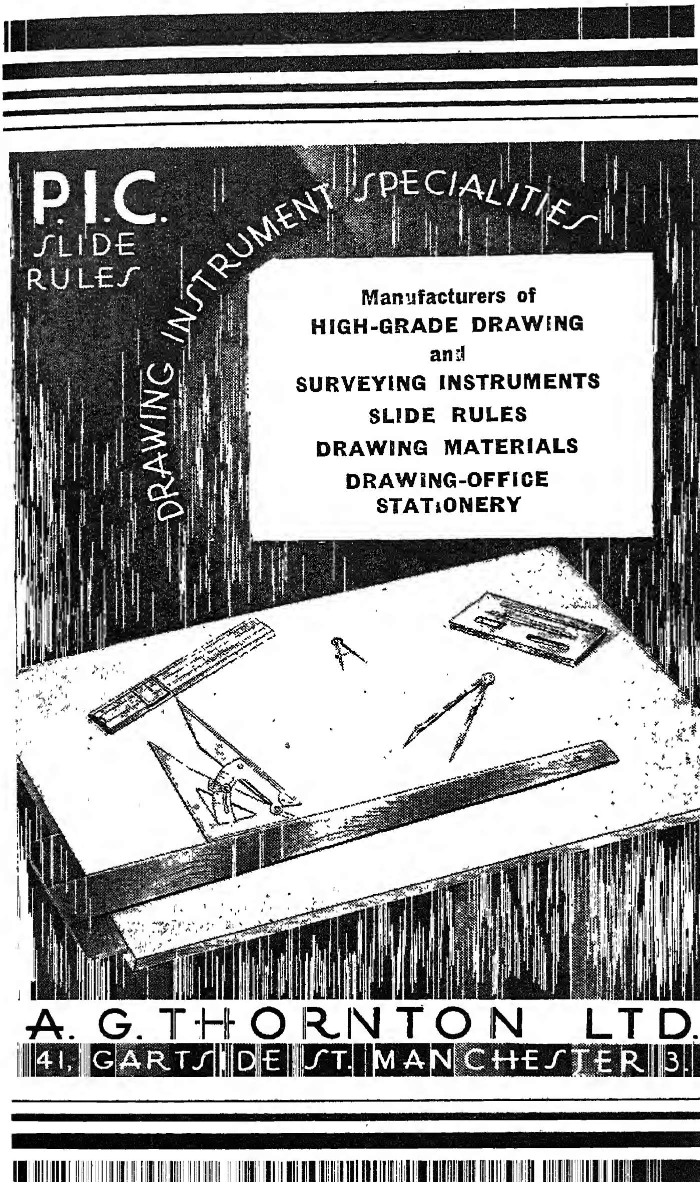
Joining :
Solder here.
Braze here.
Weld here.

Locking :
Prick punch to lock on assembly.
Solder to fix all parts on assembly.
Peen here.

Assembly Instructions :
File flush on assembly.
Cut to suit on assembly.
Bend to suit on assembly.

Tooling Instructions :
Curve to template.
Template to ordinates.
Blank dia. "XX."

Fig. 12.—Standard forms of notes on drawings.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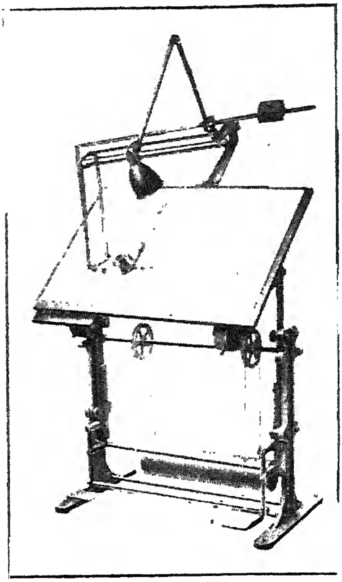

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"MAVITTA" adjustable ball-bearing drafting machines are suitable for use on any board. They are made of steel tube and the main angles are located automatically, and the intermediate angles by lock. All bright parts are chromium plated and they can be supplied with or without Micrometer adjustment of the quadrant. Models available for vertical or horizontal boards. The scales have inlaid celluloid edges and are divided to order on two edges.

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Drawing Sheets.—The following sizes are recommended by B.S.S. 308 (1943) as yielding economy by having sides of lengths which are multiples of standard widths of paper (40 in. and 30 in.). Of these those suitable for 30-in. paper are more frequently used, as 40-in. is rather cumbersome to handle.

72 in. × 40 in.†
60 in. × 40 in.†
53 in. × 30 in.† } † Dimension of roll width used.
†40 in. × 30 in†.
†40 in. × 27 in.
40 in. × 15 in.
30 in. × 20 in.
20 in. × 15 in. } Subdivisions of 40 in. × 30 in.
15 in. × 10 in.
*10 in. × $7\frac{1}{2}$ in.

The following intermediate sizes were added by Amendment No. 1 to B.S.S. 308 in January 1943, to accommodate large numbers of existing drawing boards and plan file cabinets and to conform with commercial stationery:

*30 in. × 22 in.
*27 in. × 20 in. * These sizes omitted in B.S.S. 308 (1943).
13 in. × 8 in.
10 in. × 8 in.

A further recommendation of this amendment is that all sheets should be marked with the standard sheet size at any convenient place inside border lines.

Great use is made of standard sheets printed to office requirements. Many and varied are the layouts used, but most appear to conform to B.S.S. recommendation that manufacturers' name should be positioned in bottom right-hand corner. Repetition of this in top left-hand corner, however, is seldom seen. Advantage is often taken of the printing process to include standard notes on printed sheets which will be required to appear on all drawings. The information covered is usually a selection of the following:

(1) Title space.
(2) Serial number space.
(3) Signatures space. } Common to practically all printed sheets.
(4) Manufacturer's name.
(5) Revision column.
(6) Machining abbreviations.
(7) Limits of working required for various processes.
(8) General limits except where otherwise stated on drawing.
(9) Notes regarding processing of materials and finish of delivered goods.
(10) Note stating drawing must not be scaled.
(11) Reference column to associated drawings.
(12) Space for number of drawing which is superseded or drawing which supersedes subject drawing.
(13) Space for scale indication.
(14) Space for number of drawing which is nearest equivalent to that shown.
(15) Signed statement that no equivalent drawing exists.
(16) Job or shop number for which drawing first made.
(17) Material and finish spaces.
(18) Marked-off material list.
(19) Positions of folds indicated.
(20) Table for indicating serial numbers of similar components.

Border lines approximately $\frac{1}{2}$ in. from edge are usually drawn around the sheet. A double border is sometimes used.

Where an office is repeatedly using a standard outline for a drawing and filling in specified dimensions, considerable draughting time is saved by having standard sheets printed complete with the common outline positioned on the paper ready to receive dimensions.

Co-relation of Drawings.—The modern drawing office pays considerable attention to the grouping of drawings as a means of preventing duplication and assisting the planning departments.

Drawings may be grouped in numerous ways. Some of the more important methods are described here:

Grouping by Assembly Drawings.—The various forms of this type of drawing are the General Arrangement, Assembly and Sub-Assembly (sometimes called Pre-Assembly) drawings. These all show the erection of component parts into complete units, and refer to each component by drawing number or description.

The general form is as Fig. 1, wherein the table on the right indicates the reference numbers of the components and numbers required of each. Additional components and groups of these may be added without redraughting—a feature of great importance.

An alternative method used here is that of showing the assembly drawing alone and preparing a separate sheet as material list. The latter again refers to all components together with drawing number and description of apparatus.

Grouping by Similarity.—Several methods apply here as follows:

(*a*) *Multi-part Drawings.* (*Common-view Type*): Similar components, such as studs, distance pieces, tubes, blanks, etc., may be specified to a common view with tabulated dimensions against letters. See Fig. 13. Lettered dimensions should not normally exceed four in number.

ITEM No	USED ON	A	B	C
1		4"	2"	3/8"
2		4½"	2½"	3/8"
3		6"	3"	½"
4		7"	4"	½"

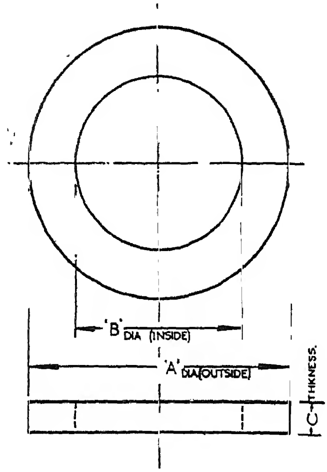


Fig. 13.—Multi-part drawing.

(*b*) *Multi-part Drawings.* (*Common Views with Figure Numbers*): Where a range of similar components is more complicated, e.g. multi-variation of similar spring contours, each main variation is drawn with lettered dimensions, allocated a figure number and components specified to component item number and figure number (see Fig. 14). The number of figures is unrestricted, but one item number may not be assigned to two figure numbers, as assembly drawings may only refer to components by drawing number and item number.

(*c*) *Multi-part Drawings*: Providing each component will be produced by a given department, several components may be drawn on one sheet even if there is no similarity between them (see Fig. 15).

Where two or more components are identical except for one or two details, it is allowed that, if the first be drawn and fully dimensioned, then other similar components may be portrayed to show dimensioned differences to the first with the added note: "All other particulars as Item 1."

This reference back to a previous item may only be of the first degree, i.e. Items 2, 3, 4, etc., may all refer back to Item 1 for majority of particulars, but Item 3 may not refer back to Item 2 if the latter in turn refers to Item 1 (see Fig. 16).

Grouping by Production Requirements.—When detailing the components

IT. NO.	FIG NO.	A	B	C	G	N
1	1	3/16"	3/16"	5/16"	28	8
2	1	1/4"	9/32"	1/4"	26	6
3	1	5/16"	5/16"	1/4"	26	5
4	1	3/8"	3/8"	5/16"	24	4
5	2	1/4"	5/16"	–	30	12
6	2	5/16"	3/8"	–	28	10
7	2	3/8"	7/16"	–	26	7
8	3	5/16"	13/32"	11/32"	28	9
9	4	3/16"	3/8"	5/16	24	13
10	4	1/4"	1/2"	7/16"	26	9
11	4	3/8"	1/2"	1/2"	28	5
12						

Fig. 14.—Common views with figure numbers.

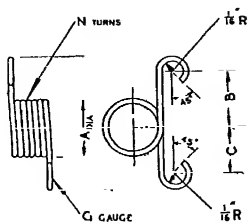


FIG 1

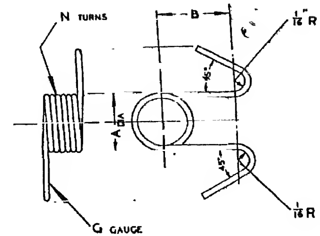


FIG 2

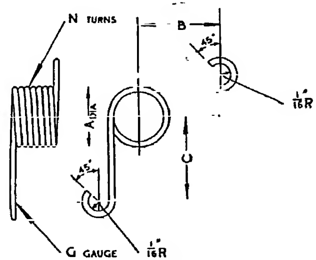


FIG 3

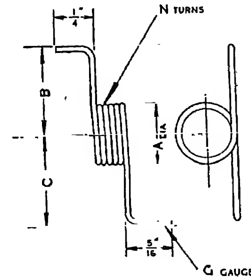


FIG 4

of any apparatus it is important that components which will be manufactured in different departments shall not appear on the same drawing, e.g. components produced in the press shop must not be specified with others which will be produced on the lathe. Fig. 15 shows such components.

Grouping by Reference Number.—A variety of methods are used here. Examples are as follows:

(*a*) *Logging Method:* Where large numbers of drawings exist of similar components and redraughting on to one or more sheets is impracticable, each drawing is endorsed with the numbers of all similar drawings. Thus, on finding one example of a group the draughtsman may refer to all others before adding to the variations.

(*b*) *Definition of Use Method:* It is always advantageous, when revising the design of a component, to know what apparatus incorporates it. This is indicated by the addition of a note to the component part drawing: "Used on Drawing Number ——."

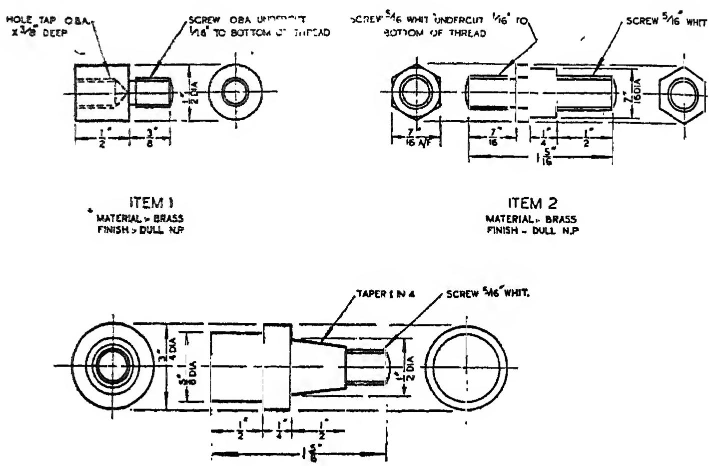


Fig. 15.—Group of components.

(*c*) *Card Index File:* In this method an up-to-date file of cards is maintained wherein each card groups all similar drawings or those appertaining to various semi-standard components, such as special washers, nuts, taps, valves, etc.

(*d*) *Reference Binder Method:* This is similar to (*c*), but information is logged on sheets from which prints may be made. The method bears amplification to the extent of showing general views for each group with salient dimensions lettered with logged values against drawing numbers.

In general, the previous policy—one drawing—one job—has now been superseded by co-relating all information with the following aims:

(1) Reduction of numbers of slightly different components.

(2) Obviating, as far as possible, the chance of having two drawings of one component.

(3) Facilitating cross-reference operations for the draughtsmen.

(4) Assisting Planning and General Administration Departments by reducing the number of variations in required components to a minimum, thereby making for more efficient works organisation.

Use of Previously Designed Components.—Where it is found that a required component may be produced by modifying one already in existence, the latter being still required, the draughtsman prepares a new drawing showing the required

modifications and, on specifying the material, instructs the operator to " USE DRG. NO. ——."

In such cases no repetition of dimensions may be made on the new drawing, as this would be a form of double dimension and thus is dangerous.

The method is mainly confined to those components which are always in considerable demand and hence always in stock, or where a large " dead " stock has been held for some time. In other cases the method is uneconomical, for the drawing office is, in effect, instructing the shops to make one component for the sole purpose of transforming it into another. Where, of course, no modification to an existing component is required, this is " picked up " on the assembly drawing as a component in the normal manner.

Projections.—*First-angle Method.*—The British Standard method of projection is recognised as First-angle Projection. Each face of the component is viewed in turn along planes at right angles. This would normally give six views, but where a view would give no additional information it is omitted. The views

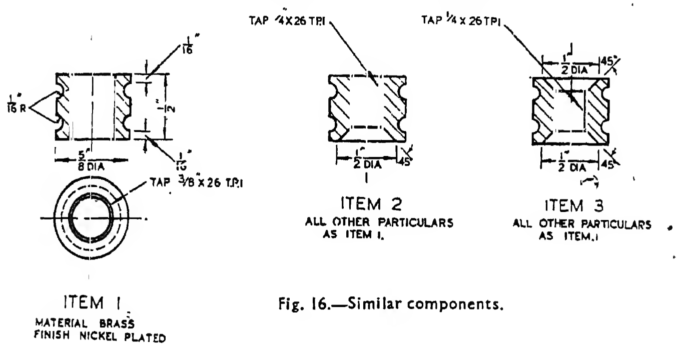


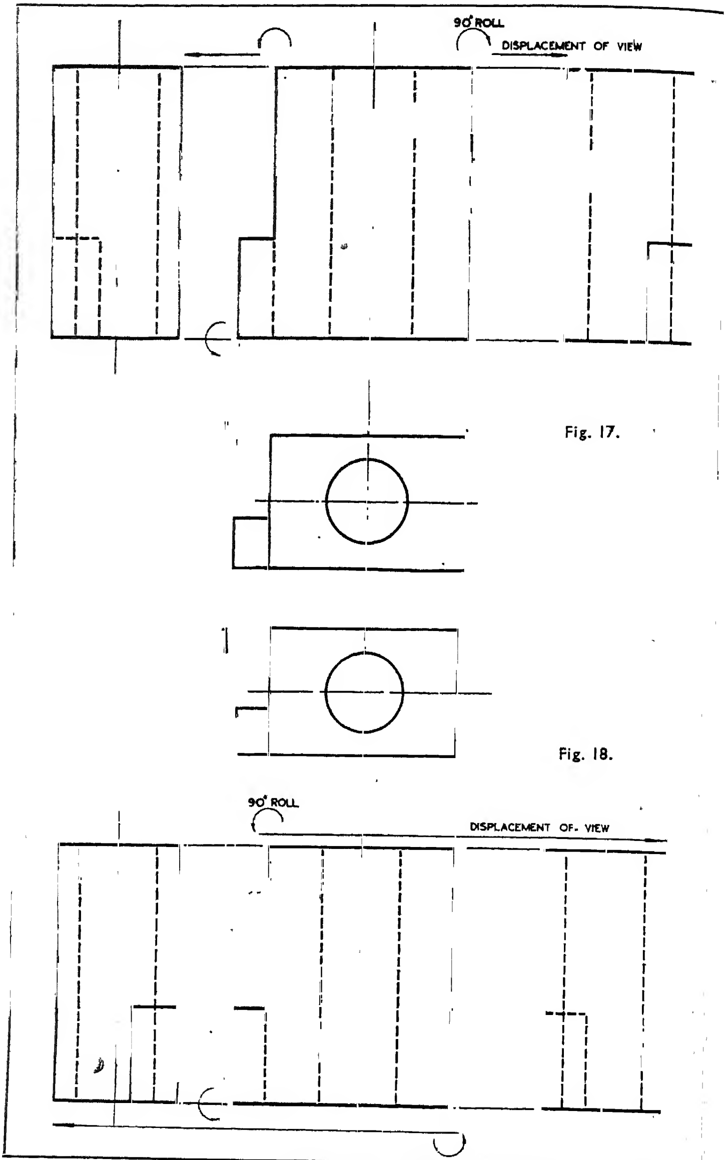
Fig. 16.—Similar components.

are so arranged that each shows the face of the component at the far side of an adjacent view, as seen in Fig. 17. If then the component, when viewed on any face, is considered to be rolled through 90 degrees in the direction of the second view, this will automatically position the next view in correct relationship to the first. The arrows and rolling lines on Fig. 17 illustrate this operation.

Third-angle Method.—Whilst the First-angle method is the generally accepted standard in this country and conforms to normal methods of Geometric Projection, certain countries, and some firms in this country, use the Third-angle method, in which each view illustrates the side of the component nearest to it on an adjacent view (Fig. 18). This shows the same component as for the First-angle method above. In this case the component, when viewed on any face, is considered to be rolled through 90 degrees in the opposite direction to the second view, then lifted bodily across the drawing and viewed as before. This operation is illustrated by arrows and rolling lines in Fig. 18.

Where large drawings are in evidence, the Third-angle method has much to commend it to the draughtsman, for it considerably shortens the distance of projection. If for this, or any other reason, the Third-angle method is used for a view on a drawing, an arrow is shown pointing in the direction of view, and the projected view labelled "View in direction of Arrow X." By this means confusion is avoided. Where Third-angle projection is adopted by an office as standard practice, all drawings are endorsed " Third-angle Projection " in bold characters.

Developments.—*Blank Sizes.*—Only the simplest calculations should be left to the operator. If a blank size is necessary before commencing production of a component, the draughtsman must perform all calculations and quote the required information on the drawing. In these calculations it is usual to assume that no stretch will occur in forming operations, hence the surface area of component will be that of the required blank. This assumption normally allows sufficient excess



Figs. 17 and 18.—First- and third-angle projections.

material for final trimming. Where considerable stretch takes place, calculations are based on the assumption that the volume of the blank will be the same as that of the resulting component. In the case of components having intricate form, it is more convenient to use a third method where it is assumed that the weight of the blank will be that of the component. All three methods involve a full knowledge of mensuration, stereometry, longimetry, and planimetry.

All calculations of theoretical size are quoted as approximate.

Developed Contours.—As with blank sizes, these should be evaluated and specified by the draughtsman. So many books on solid geometry show methods of developing resultant curves of intersecting solids that repetition is not necessary here. Contours are developed by normal draughting methods on the drawing-board and ordinate values scaled off the layout.

Quotation of the curve on the drawing should be by rectangular co-ordinates, as these are most easily set up. If welding is used to fix the two components, then allowance must be made for the weld.

The curves must be quoted to a good degree of accuracy where the components

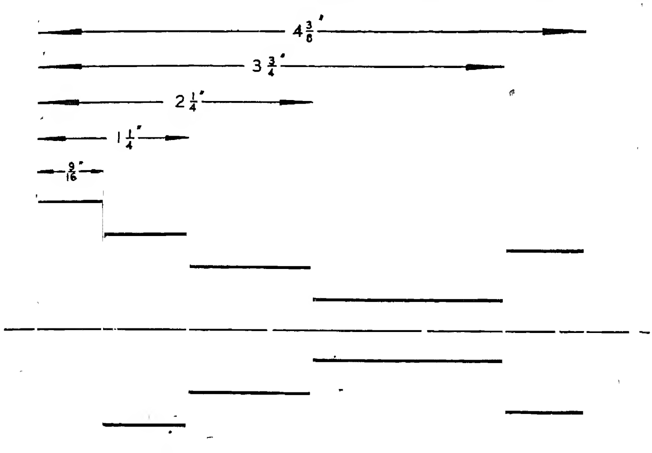


Fig. 19.—Dimensions from a common datum.

are of any real size, for modification, after contour cutting, is a slow and laborious process. Simple shapes, such as cones fabricated from sheet metal, need no evaluation, for the sheet-metal worker has his own tables covering these requirements.

Layouts.—Where any degree of intricacy of design is in evidence, the draughtsman prepares a preliminary drawing which is used in several ways to achieve finality in design. This form of drawing is termed a layout. Various methods of preparation are used, selection being according to the salient features of the required designs. Where a component is required to match with others, it is usual to locate the matching surfaces first, then follow by building the component between the boundaries set up. In all cases the draughtsman must first visualise the component, or apparatus, before commencing to draw, even if the mental picture obtained is very indistinct and incomplete. By putting on paper his first impressions the draughtsman develops, improves, and completes the design, thereby using the drawing-board as an instrument.

Layouts must be drawn as accurately to scale as possible, and all manner of artifices are used to this end. Some of the standard methods are as follows:

(1) Scaling all dimensions from a common datum (Fig. 19).
(2) Drawing to an enlarged scale, usually 5 to 1 or 10 to 1 for small components.

The latter will give an effective accuracy of 0·001 in. if drawn to nearest $\frac{1}{100}$ in. (normally highest standard for all dimensions).

(3) Checking all settings of dividers and compasses by setting off diameters and measuring these. This method may be amplified in the case of dividers by stepping off ten steps and checking the aggregate length.

(4) All lines maintained as thin as possible to limit of visibility, using chisel-pointed pencil of grade 3H or 4H. This avoids errors due to thickness of line.

(5) Setting all angles by means of tangent tables. Here a 10-in. base line is used and a perpendicular erected of length ten times the tangent ratio of the angle required. The line completing the triangle then accurately sets up the required angle (Fig. 20).

(6) When erecting long perpendiculars from a base line the set square is discarded. Each vertical is set up by compass or trammels, using conventional construction for dividing a line at right angles (Fig. 21).

The above methods, with the exception of (1) and (2), considerably retard drawing speed. They are therefore used only where accuracy of layout is of

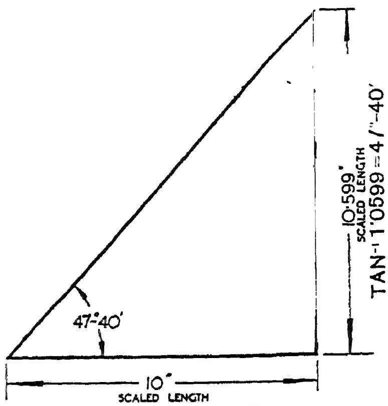


Fig. 20.—Setting up angles.

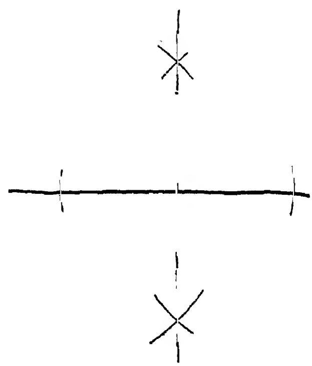


Fig. 21.—Drawing line at right angles.

extreme importance. A hard, thick cartridge paper should always be used to receive the drawing where accuracy is of importance.

Modifications.—The continual improvement of design of components necessitates careful working in the drawing office. It is usual to maintain complete and accurate record of all revisions for future reference. These records are of two forms :

(1) Logging of abbreviated description of the change effected on the drawing. A special table (Fig. 1) is usually included in the standard form of printed sheet. This allocates a number to the change, records the date on which it was effected, the nature of the change, and signatures of those persons responsible.

(2) The completion of a notice of Revised Drawing on the lines shown in Fig. 22. Here a full and detailed report is made both of superseded and new conditions of design. Remarks concerning reason for the change and any other information likely to be of future interest is also logged, together with the departments which will be affected.

Before changing the information conveyed by a drawing the draughtsman must:

(1) Ensure that no similar component will be duplicated by the issue of changed instructions.

(2) Ensure that all assembly drawings using the component concerned will accommodate the component in its new form.

(3) Ascertain that the change is really necessary or will " earn its keep " by improving production methods.

(4) Investigate the possibility of an existing similar component proving equally beneficial as would the revised version of the component to be changed.

If these conditions are satisfied, then the modification is effected.

It is necessary to issue revised instructions for all changes on the drawing which alter the physical characteristics of the component. If a drawing is changed without affecting the component (e.g. redrawn as before, or retraced), then a revision is unnecessary unless a change is made to the actual component or work's routine demands notification.

Many offices indicate the position of revised instructions by a distinguishing mark on the drawing alongside the new instructions. This mark may take the form of 1 or 2, or be of any design which will clearly distinguish it from normal inscriptions.

Layout of Drawings.—All inscriptions on the drawing-sheet are arranged with sufficient clear space around them to give isolation from all others. These clear spaces are of great importance to facilitate reading, and each space is of such

NOTICE OF REVISED DRAWING No: AG 96347

TITLE: 8" BEARING PEDESTAL. GENERAL ARRANGEMENT

THE FOLLOWING REVISIONS HAVE BEEN EFFECTED.—

1 MODIFIED REFERENCE ITEM 16 (WAS A 92390-1 NOW A 92563-2) DELETED ITEM 17

2 ADDED ITEM 23

REMARKS.	CHANGE DUE TO:	
	SIGNED	DATE
EXISTING STOCK, TO BE / NOT TO BE MODIFIED / SCRAPPED	COPIES TO DEPTS:-	
	D.O. REF ....1..	
	STORES 1	
	INSP. 1	

Fig. 22.—Notice of revised drawing.

magnitude as to impart a general impression of balanced layout of all the information logged on the sheet. (See Fig. 15.)

Drawings of the multi-component type are so arranged that each component is clearly isolated. No dividing lines are drawn between the components, but sufficient space is allowed between them that if all components were cut out of the sheet, then each would be contained in its own rectangle.

Where any fixed working position is in evidence the component is shown as viewed by the operator. An example of this is where a component will be produced in the lathe. Here one end must be contained in the chuck of the machine at the left-hand side of the operator. This end must be shown on the left-hand side of the sheet when the drawing is in the reading position.

Notes may not be made common to a number of views by linking with arrows, but each component must appear as a drawing alone. Where general notes are required, these are neatly grouped together with sufficient space between each for purposes of differentiation. Designation of letters or numerals to general notes facilitates reference.

Plan and elevation views are so arranged as either to view the apparatus as seen in its normal position in service or, where this is indeterminate, in the most advantageous position for the operator.

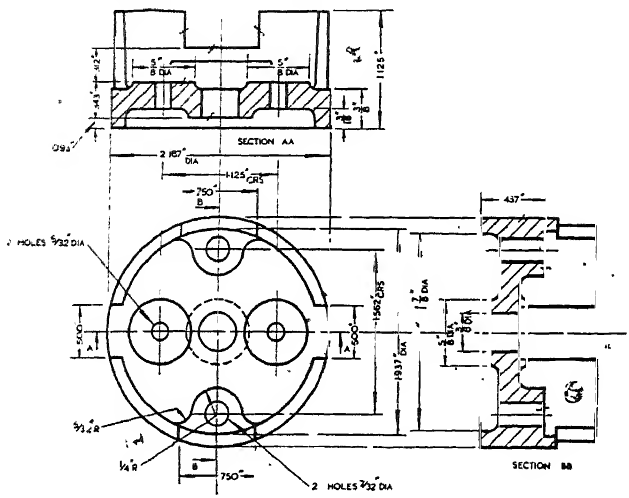
On assembly drawings the components are arranged in the numerical order in which they will be assembled. If a number of groups of components are in evidence then, where possible, all variations of a component are quoted in *grouping*

order before proceeding to the next component of the initial group. Component numbers may not be changed for any reason.

On all new drawings it is endeavoured that sufficient space is allowed for reasonable future expansion. On a drawing being retraced this is again arranged for unless it is obvious that all possible variations have been incorporated.

Sectioning Methods.—When it is required to show interior contours, it is accepted practice to draw the profile given by cutting the component along any arbitrary line. To indicate this feature the sectioned or cut contours are cross-hatched thus // ////// at 45 degrees to the edges of the drawing-sheet. These sections, as they are termed, are very common on drawings of castings, where usually the patternmaker will take further sections to those shown by the draughtsman before producing patterns.

Indication of lines of section are as shown in Fig. 23. Arrows are arranged



ITEM 1
MATERIAL ALUMINIUM
FINISH -

Fig. 23.—Indication of line of section.

pointing normal to the line of section in the direction the profile is seen, with the arrow point abutting the line. Letters are designated to each arrow for discriminating purposes.

The choice of position of section lines is a matter of experience, but the general aim should be to illustrate as many of the characteristics of the component as possible with one sectioned view. Sections may be taken by lines at various angles as shown or, if only a small portion needs elucidation, a part section may be shown.

Cross-hatching.—The spacing of cross-hatching should be uniform for each area. Some offices prefer a close spacing, as this is more easily rendered uniform. Others require a wide spacing for large areas and corresponding narrow spacing for small areas of section. The effect of this method is to emphasise the smaller areas, thereby attracting attention.

In the past there have been various conventional forms of cross-hatching used to indicate different materials. B.S.S. 308 (1927) considers these undesirable and restricts this method to the materials wood and concrete only. The use of colours

too is deprecated, but where these are used brown is recommended for centre lines and blue for dimension lines with black arrow-heads. The specification also recommends the use of brown instead of red, and that blue be a mixture of Prussian blue and white where photo printing is required. B.S.S. 308 (1943) does not recommend the colouring of drawings where reproductions are required. In any case, different materials should be specified by notes on the drawings and, in the event of special methods of cross-hatching or colouring being used, a key should be included on the drawing.

As a result of the above specification special colouring and cross-hatching methods are rarely seen on engineering drawings. Their use is now almost entirely restricted to drawings for large tenders.

Tracings and Technique.—All tracings should be executed on finest quality tracing cloth. Various preparations are available for degreasing the cloth, and if these should be unobtainable a good-quality French chalk will do equally well if the tracing be carefully rubbed with a small quantity.

Either the glossy or matt side of the cloth may be used, but best results are generally obtained by using the glossy side.

Tracing cloth should, if possible, be set up late in the afternoon and left fixed to the board overnight. Any inherent stretch may then be taken up before commencing work next morning. The hands should not be rested on the cloth any more than necessary, particularly in warm weather, for moisture will stain the cloth and cause it to stretch.

All workmanship should be of the highest grade possible, for a carefully handled tracing has a useful life of up to twenty years and more.

With the improved transparency and working life of detail-tracing papers rendering pencil originals more suitable for photo-copying, it would appear that the scope of work for the tracer has been somewhat curtailed. In some ways this is the case but, although there is less real tracing work, there are many more types of work passed to the tracing section than fifteen or twenty years ago. Much of the pure draughting of diagrams is now allocated to tracers who may only receive verbal or written instructions as a draughtsman. It seems likely that tracers will eventually do the work previously effected by the draughtsmen, who in turn are becoming up-graded as engineering draughtsmen able to make decisions for themselves and complete all calculations necessary for design.

Tracing, however, will always be retained for those drawings which will be in fair demand, and this should mean an improvement in the already high standard of workmanship achieved by many offices.

The usual procedure is that the draughtsman prepares his drawing, either as an original for tracing or suitable for direct issue. The former case is now restricted to large, intricate jobs, where many days, or even weeks, will have to be spent on the board and where the extra time spent in making the drawing suitable for printing would be greater than time required to trace the complete job. Using this method, the draughtsman aims to cut down his time by avoiding the use of ink and by taking no real pains to render a very neat job. This is all left to the tracer, who may be relied upon to do a certain amount of tidying up and to improve the general layout of the drawing. Before handing the original to the tracer the draughtsman ensures that his drawing is correct in all details by a careful check, as it is most disappointing for a tracer to find that corrections are necessary after completing the tracing.

Where a drawing has been issued in pencil and ink direct from the draughtsman, the print room advises the drawing office when the original shows such signs of wear that a tracing should be made. The drawing original is withdrawn from file and traced. A few extra rules apply here as follows:

(1) Sufficient room must again be allowed for possible expansion.

(2) Where modifications have been effected the last two recorded revision notes only are copied on to the tracing.

(3) Any cancelled components shown (these will have been crossed out on the revision being effected) must be traced and once more crossed out neatly by the tracer. (This maintains complete record.)

(4) New prints are not issued unless a further revision is effected at time of retracing.

(5) The draughtsman who originally prepared the drawing checks the tracing

and signs same before it is passed to the checker. Where the draughtsman is not available the tracer records his name in the "Drawn By" space and the tracing is passed direct to the checker.

Tolerance Quotation.—There are several ways of indicating required accuracy of dimensions on components. B.S.S. 308 (1927) states that: "When Tolerances are not shown, dimensions which are not of great importance may be given in vulgar fractions. Where a greater degree of accuracy is required, the dimensions are to be given in decimals." A future B.S.S. is to be issued on the specification of tolerancing.

Light and medium engineering dimensions quoted in vulgar fractions may be expected to be produced to rule reading accuracy, i.e. to nearest $\frac{1}{64}$ in. If decimals alone are quoted, a first-class tool-maker will usually work to the nearest $\frac{1}{1000}$ in.

For lathe work quotation of diameters by vulgar fractions is usually interpreted as $\pm$ 0·005 in., longitudinal dimensions in this form are again to rule reading accuracy.

Where a greater degree of accuracy is required to that above, the actual tolerance is usually quoted between two limits thus:

$$2{\cdot}563 \begin{smallmatrix} + & 0{\cdot}001 \\ - & 0{\cdot}003 \end{smallmatrix} \ (a)$$

$$2{\cdot}563 \begin{smallmatrix} + & 0{\cdot}000 \\ - & 0{\cdot}002 \end{smallmatrix} \ (b)$$

$$2{\cdot}563 \begin{smallmatrix} + & 0{\cdot}003 \\ - & 0{\cdot}000 \end{smallmatrix} \ (c)$$

$$2{\cdot}563 \pm 0{\cdot}002 \ (d)$$

Examples (*a*) and (*d*) are of bilateral tolerance.

Examples (*b*) and (*c*) are of unilateral toe rance.

For limits allowable on dimensions for various classes of fits the reader is referred to B.S.S. 164. This gives definitions of terms, together with recommendations on tolerance calculations.

Typical Components—Springs.—The manufacture of springs to specification may be termed a specialised art, although results may be predetermined by calculations to a fair degree of accuracy.

When specifying springs on drawings it is usual to quote physical dimensions, i.e. number of turns, diameter of coils, free length, and gauge of material. In addition, information of the capabilities required of the spring should also be quoted as follows:

"Load when deflected X in.";
"Load when deflected Y in.";
"Spring must be capable of Z in. deflection";
where X, Y, and Z are constants.

Moulded Products.—Drawings of castings and other forms of moulded components are required completely designed by the draughtsman. He must understand at least the fundamentals of the process involved, quote any tapers required for pattern withdrawal, and so dimension the drawing that moulding methods and parting lines are self-evident.

Inserts for plastic moulding processes are usually shown as separate views on the moulding drawing. Should these be supplied to the moulder, a separate drawing is prepared and its serial number logged on the component part drawing.

Free use is made of sectional views either of the full or part-section types, and a general effort made to clean up dimension layout to facilitate reading of the drawing.

All holes and machined surfaces required are shown and specified on the component drawing, for this information is important to the tool and pattern maker.

Welded Assemblies.—For the sheet-metal and welding departments the complete structure is shown in assembled state. No detailing of separate components is carried out unless large-scale production is anticipated.

Machining instructions must again appear on the drawing, so that the workman may allow for distortion during manufacture.

Press Tool Work.—Developed blank sizes are quoted for all components, and where folding is required a separate view of the blank is included.

In general, drawings for specialised processes are always prepared on lines in sympathy with the characteristics of the process. A considerable amount of

liaison work is necessary on the part of the draughtsman in contact with the department concerned, and every effort is made to simplify the work of the operator by perceiving his difficulties and visualising methods whereby these may be surmounted.

Where and When Drawings are Necessary.—It is common practice that drawings are made for every component used in the works. The only exceptions to this rule are:

(1) Standard items, e.g. nuts, screw, washers, etc., which may be briefly specified by description—Screw OBA × ½ in. long. CH.HD. BRASS.

(2) Components completely manufactured by simple cutting off standard bar sections. These again may be specified by brief description—Angle 1½ in. × 1½ in. × $\frac{3}{16}$ in. × 6 ft. 2 in. long.

If, however, any small variation from standard is required for (1), e.g. threads required undercut, or any operation in addition to plain cut off at 90 degrees for (2), e.g. ends to be chamfered or radiused, then a drawing must be issued to convey these instructions.

When revising the design of a component, a new drawing number is required if the new version of the component is not interchangeable with the previous design. If the new version is completely interchangeable, then the existing drawing *number* is retained even if a new drawing-*sheet* is required.

Materials and Equipment.—All materials and equipment should be of the highest quality obtainable. This is becoming more recognised, and new offices are often almost lavishly equipped with tilting boards, cushion-seated stools, etc.

A good-quality, unprepared tracing-detail or detail paper is used for pencil drawings. Where the original will be required for reproduction purposes over a long period of time, it is usual to prepare a tracing on treated linen.

The following qualities of materials are the chief concern of the draughtsman:

Paper (Tracing-detail or Detail)

(1) Reception of ink and pencil lines.
(2) Printing exposure times.
(3) Erasing properties.
(4) Ageing. (Some papers discolour; others become brittle with age.)
(5) General ability to withstand handling without becoming opaque.

Pencils

(1) Grain of lead.
(2) Combined hardness of lead with density of inscription.
(3) Quality of wood casing and general finish.

Ink

(1) Covering power.
(2) Drying time in tracing pen and on drawing.
(3) Erasing properties.

Erasers

For Pencil Work

(1) Degree of bite on paper, i.e. lack of tendency for erasure to become smooth on rubbing.
(2) Durability.
(3) Shape suitable for holding.

For Ink Work

(1) Abrasive content.
(2) Polishing properties when rubbed lightly on tracing cloth.
(3) Durability.

Tracing Cloth

(1) Reception of ink.
(2) Printing exposure times.
(3) Erasing properties.
(4) Grain.

Equipment

The draughtsman is supplied with drawing-board, stool, and reference table. The board is fitted with tee square, parallel motion or draughting machine, and all other equipment is the responsibility of the draughtsman. He is required then to equip himself with instruments, set squares, scales, and any other special gear he may require, such as slide rules, curves, etc. Trammels are usually part of the

office equipment, and pencils, rubbers, ink, and paper are all supplied by the employer.

Data Sheets.—In the course of his work the draughtsman is repeatedly using components of standard dimensions. These are so numerous that reference must be made to written records for quotation purposes. In order to save time and in the case of some components where all records do not agree in various pocket-books, etc., it is usual for the office to compile a binder of reference or data sheets to maintain uniformity of quotation. The information for these sheets is compiled from various sources, the chief of these being the British Standard Specifications. The file, once started, soon assumes large proportions, and the draughtsmen often suggest additions which have been found advisable.

These data sheets give information of such standard components as screw thread and head dimensions, taper pins, nuts, washers, flanges for pipe work, rolled-steel joist dimensions, etc. The file is often amplified by including tool sizes, such as number and letter drill and taper reamer dimensions, detailed information of particular components standardised by the works, technical data of frequent use in the field of engineering covered by the office, and, in the case of components, it is usual to indicate whether a stock is maintained by the stores.

The sheets are prepared as normal originals and prints made by the printing room to office requirements. A useful size of sheet will be found to be 10 in. x 8 in., as this is suitable for standard commercial files, which may be used for binding.

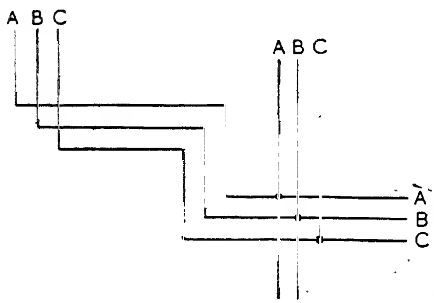


Fig. 24.—Indication of Intersecting points.

Diagrams.—Where the detailing of components would serve no useful purpose, due to these being necessarily arranged to suit each particular equipment on completion of assembly, the drawing office prepares a diagram to cover instructions. This quotes no dimensions, but shows an outline of the equipment with the components in position. The application of this practice is seen in oil-piping diagrams for dynamic machinery where lubricating oil is fed to remote bearings by pipes from a common pressure pump; wiring, schematic, and winding diagrams for the inter-connection of components in all forms of electrical gear, etc. The diagram therefore serves as a guide to the erector, who uses his own ingenuity to effect connection between the points indicated. (Where considerable initiative would be necessary, the draughtsman indicates the approximate path of these connections.)

For all diagrams the outline of the assembled equipment or apparatus is shown in thin, full lines in sufficient detail to illustrate salient features. Connections are then superimposed in heavy, bold lines so that these stand out against the outlined portion. All intersecting points of the connections are positively indicated as in Fig. 24.

For electrical wiring diagrams (sometimes termed wiring diagrams) all portions of the equipment are shown as viewed by the erector on making connections. The rules of projection are suspended in these cases. The wiring diagram shows the physical relationship between the various components forming the apparatus, and connections are drawn from point to point as will be actually made by the erector. All components which are separately mounted or form definite components alone are enclosed in dotted lines, e.g. remote-control push-button stations on automatic contactor control equipments.

Where the apparatus depends upon an intricate form of control and connections are thus of a complicated nature, a schematic or theoretical diagram is included alongside the wiring diagram. The schematic diagram disregards the physical

relationship between components but arranges these in their electrical relationship. This enables the engineer to follow the form of control adopted without carefully tracing out numerous connections, and is a means of checking the correctness of all connections.

It is usual to designate a number to each point of different potential on electrical diagrams, for purposes of identification. These are arranged on the schematic diagram and transposed to the wiring diagram on completion.

Print-file Operation.—The supply of up-to-date prints to the operatives is a major responsibility of the drawing office. On a drawing being completed it is forwarded, via the planning departments concerned, to the printing room, where copies are made according to requirements. These copies are routed to files located in the works and offices, where they are usually arranged in numerical order. Meantime, instructions have reached the shop's foreman, via the various planning departments, and the operator requests the drawing number indicated in his instructions.

Prints are only issued against loan tickets, which bear the number of print, operator's signature, and his department. The ticket is then filed in place of the drawing and only scrapped on return of the print.

This procedure enables the print-file attendant to locate an out-of-date print on receipt of a modified copy. Under this condition all existing prints are scrapped before the new version is issued. The attendant therefore collects all copies on file and any on loan, and then issues the revised copies. Where a loaned copy cannot be found by the operator, record is made of the drawing number, revision number, and date in a special book so that, should the print be discovered in the production shops at a later date, the print-file attendant is released from responsibility.

Where a design change is urgently required the draughtsman, on his own responsibility, by-passes the above system by making direct contact with the foreman producing the apparatus. He is either informed that a modification is necessary and to cease work, or given an advance copy duly modified pending receipt of official print. Such methods are only used in extreme emergency where saving can be effected. The revision must of course follow through the usual channels, and is generally endorsed " For Record Purposes " or " As per verbal Instructions."

Ordering Components from Outside Suppliers.—Where components will be required from outside suppliers, to their design, for assembly in completed apparatus, these must be ordered as soon as possible. On decisions being reached in early design stages, the draughtsman advises the purchasing department what components will be required and in what number. For all such instructions experience has shown that a copy of a drawing specifying the component must accompany the order if safety is to be assured.

These drawings are usually termed ordering sketches and are produced by the draughtsman when necessary. Only the salient features of the apparatus are shown, together with manufacturer's name and catalogue number where alternative sources of supply will not be available. In all other respects the order sketch is identical to the normal form of drawing, as, too, is the method of distribution.

Where components are required to be made by outside specialist manufacturers to buyer's design, the drawing is prepared on purely orthodox lines and a copy forwarded with the order. In this case, the outside supplier is treated in the same manner as an additional department of the works, but considerable care must be taken when modifying the design of these components. Should a revision be necessary, it is advisable to ascertain the following information:

(1) Outstanding orders.
(2) Raw materials stocked by supplier.
(3) Work actually in progress.
(4) Contracts placed.

On effecting an agreed revision to design, the new drawing is forwarded. This may bear a rubber-stamp impression stating that it supersedes all copies issued before a quoted date.

Office Organisation.—There are three main forms of organisation applied to the drawing office:

(1) Individual draughtsmen and tracers working direct to chief draughtsman.
(2) Centralised sectioning system.
(3) De-centralised sectioning system.

(1) In small works, where the number of draughtsmen is not large, each man is directly controlled by the chief draughtsman. All work received is allocated to suitable available men and returned on completion for checking. The chief draughtsman therefore acts as office manager and checker. The aim of the chief draughtsman, under these conditions, is to vary the work of each subordinate so that all are well acquainted with the variety of products produced.

(2) Wherever possible the drawing office is divided into sections, each of which specialises in a given range of products. Higher efficiency is achieved by this means because the draughtsmen can concentrate on a given line of products. Where staff numbers permit, each section is allocated a section leader who, in effect, runs his section as a separate office under the jurisdiction of the office manager. The section leader may have a checker for his section or may, as in (1) above, perform these duties himself.

(3) Where a very large works is concerned with the manufacture of a wide variety of products, one office alone would have severe disadvantages, due to size and distance from some of the outlying manufacturing departments. In this case, branch offices are arranged to serve these departments with a main drawing office as centre. Each branch office is allocated its chief draughtsman who, like that of (1), will have full responsibility for discipline, allocation of work, and designs evolved. He is, however, subordinate to the manager of the main drawing office and, in effect, works on his behalf. If his office assumes sufficiently large proportions, he too will sectionalise as in (2).

All three methods involve tracing staff. In the case of (1) they form an integral part of the office staff. For centralised control they are usually considered a separate section, and for the de-centralised methods each branch office has its own tracers.

Routing of Work in the Drawing Office.—All work allocated to the drawing office is viewed by the office manager, both at time of receipt and despatch. The sources of instructions are usually the engineers' departments, sales offices, or management, and instructions are generally given in writing. The route followed is then in line with the general plan given in Fig. 25.

The office manager views the instructions, formulates a general plan of attack, and passes all information to the section leader concerned, who in turn records salient features and, in the case of large jobs, allocates it to a senior draughtsman of his section of the office. This man does all the real design work necessary by preparing his layout and evolving any new apparatus which will be required. He may, if pressed for time, allocate certain details to any available junior draughtsman and again very simple detailing work to trainees. Whilst this work is being done for him, he prepares the main assembly drawings which will co-ordinate the work of his juniors, and may retain for his personal attention such components that appear to require careful development. In the meantime he will answer queries raised by his juniors and generally supervise the development of the whole apparatus in line with written instructions and results of personal contact with his superiors. As the work he has "farmed out" is completed, it is returned to him for consideration, drawing numbers having been allocated by him in advance to facilitate his progress on assembly drawings. Eventually, on the completion of all drawings, these he collects and passes to the checker, together with all reference prints of any existing components he had incorporated. It may be that certain components will be required in advance of others where the manufacturing process involved is of long duration. In such cases, he ensures that the respective drawings are passed to the checker in advance and that reference prints are included when the final job is handed over for complete check. In this manner central control of design is obtained. Each draughtsman signs all drawings he personally prepares, and any tracings made are first signed by the tracer and then checked by the draughtsman before signature.

The checker verifies all information and ensures that nothing is omitted before passing all new and revised drawings to the office manager or section leader. Reference prints are usually returned to the drawing office reference file at this stage.

The office manager finally inspects and approves all drawings issued before these are forwarded to the works' planning departments concerned. Here each component is considered from a manufacturing point of view, decisions are made as

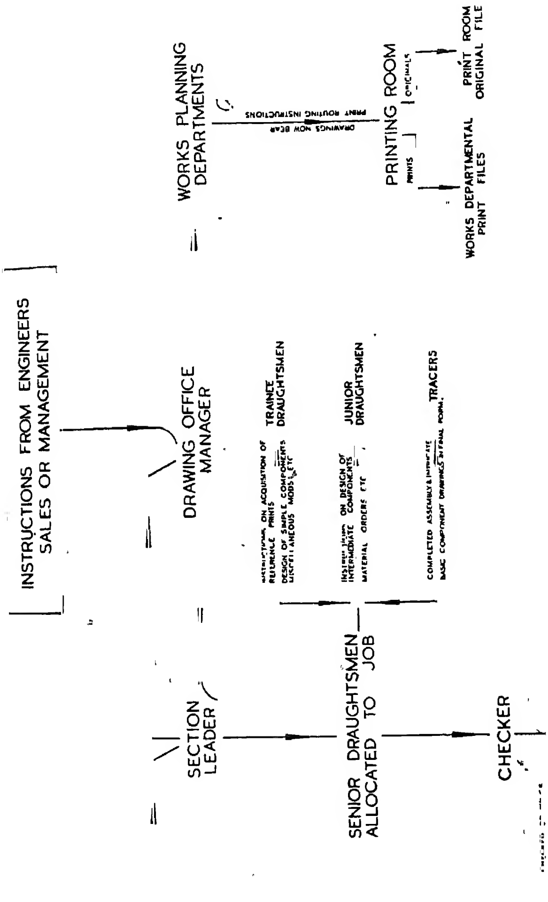


Fig. 25.—Route diagram.

to where, when, and how each is to be made, and instructions recorded as to which of the works' print files will be allocated copies of the drawings.

Finally, the drawings are forwarded to the printing or copying room, where the latter instructions are fulfilled.

The above route is, of course, only for very large jobs. Where comparatively simple equipments are required, these are allocated direct to a junior draughtsman by the section leader, and the simplest work is given to the trainee.

Responsibility for Information on Drawings.—By virtue of his position, the chief draughtsman or drawing office manager assumes full responsibility to his employers that all details on all drawings issued will be correct. It is his work to see that those under his charge are of such efficiency and ability that mistakes do not occur. Errors cannot, of course, be entirely eliminated, but it is to be expected that the prestige of the office will almost entirely depend upon the number of errors discovered on production drawings irrespective of the amount of good work performed by individual members of the staff.

In the case of a specific error, however, this is the prime responsibility of the individual who quotes the incorrect information on paper. The draughtsman therefore is mainly responsible for the errors on his drawing, and must ensure, by every means of cross check available to him, that all logged information is accurate. A tracing error is the responsibility of the tracer in like manner.

A checker is usually employed to verify all information quoted on drawings. He is required as a double check on the grounds that the draughtsman is naturally biased towards his own decisions, and so a second opinion should be obtained. If an error escapes the attention of the checker, then he is obviously inefficient, but the error was made by the draughtsman. Hence the error is the prime responsibility of the draughtsman, and secondly that of the checker who failed to discover it.

On receipt of notification from the shops of an error on a drawing, it is the first aim of all concerned to put the matter right. Any investigations or "inquests" are held after corrections have been effected. Any changed instructions must be treated as revisions to the drawing, and the department at fault should be logged in the remarks column of the "Notice of Revised Drawing."

The chief draughtsman usually maintains a log of each member of his staff, wherein both good work performed and errors are recorded. By this means he is able to maintain an up-to-date opinion of each individual under his control.

Checking.—There are three broad types of error possible on drawings:

(1) Incorrect quotation.
(2) Omitted information.
(3) Repeated information.

Each of these is borne in mind by the checker when viewing the drawings allocated to him.

(1) The only sure method of verifying information on drawings is to refer personally to written records of all references made on the drawings. The checker is also careful always to "check the drawing to the job and not the job to the drawing," i.e. when verifying quoted references the drawing number quoted is withdrawn from file and verified as being the correct component. For dimensional checks each dimension is first scaled off the draughtsman's layout and then the drawing dimension examined.

(2) On completing (1) for each component, it is next verified that sufficient information to make the component direct from dimensions is given. A good method here, where intricate components are concerned, is to peruse each contour as if it were being marked out. Positions of holes are taken in turn, ensuring that full location is quoted.

(3) Finally, the drawing is scrutinised for repeated information, as is the complete job.

The above three forms of check may be made simultaneously for each component and the apparatus as a whole, or three separate checks may be effected.

It is usual for the checker to obtain a print off all drawings to be checked before commencing his work. Corrections may be indicated on the prints in different colours (red for (1), blue for (2), green for (3), and yellow for added comments, etc.), or he may prefer to compile a list of corrections in the form of a report. For large jobs a combination of both methods is sometimes used.

As each item of information is verified it is marked with a tick (✓), thereby enabling the checker to ensure that nothing has been missed.

The checker occupies a position of prestige in the office, and is therefore keen to retain the accuracy of his decisions. He does not like to find numerous errors on drawings, for this makes him consider the possibility of having missed other mistakes. On the other hand, to have found no error on a large job raises the question of whether a perfect drawing has arrived for his attention.

Filing Drawings.—The normal method of filing is to arrange plan files, of suitable sizes to accommodate standard sheets lying flat, so that the originals may be accommodated in numerical order. Some offices file drawings by the type of equipment depicted thereon, but choice of method is mainly determined by local conditions.

Where any number of persons require access to the filed drawings, records are maintained of all loans. The borrower fills in a printed form as in the case of the print file, and in the same manner the draughtsman is held responsible for the drawing until it is returned. The chief draughtsman is usually required to countersign requests for originals.

A recent development in this field is the photographing of all drawings for purposes of reproduction and filing. Considerable filing space is saved by this method and, what is more important, reproductions are not restricted to the scale used on draughting, originals may be reproduced from prints and pencil drawings reproduced with increased clarity to that of the original drawing. It is usual to reproduce negatives measuring $6\frac{1}{2}$ in. $\times$ $4\frac{3}{4}$ in. for filing purposes, and each is enclosed in a transparent envelope to protect it from damage. These envelopes are filed in fireproof cabinets arranged in the form of a card index file. Duplicate originals are often made, one set being held for normal use, the other held in reserve in a remote location should the former be destroyed by enemy action in time of war.

Reproduction of Drawings.—The printing room, where all reproductions are made, is usually under the jurisdiction of the chief draughtsman, for he is responsible for all drawings, even those in the workshops.

There are several methods of reproducing drawings, the chief being as follows :

(1) Blue printing.
(2) Dyeline printing.
(3) By " photostat " methods.
(4) By normal photographic methods.
(5) By photographic methods on metal sheets.

Blue Printing.—For small-quantity production the only apparatus required is a printing frame (normal photographic type), blue-print paper, original drawing, and water. The exposure is effected by sunlight, and water is the only medium necessary for combined development and fixing. The prints thus obtained will retain inscriptions over quite long periods of time, and are negative prints, i.e. black lines are reproduced white on a blue ground.

Where very large quantities of prints are required a continuous-type printing machine is installed, together with a rotary drying machine. Capital costs of such equipment are high, hence for medium demand the " Dyeline " process is more usual.

Dyeline Printing.—A feature of this method is that positive prints are directly obtained. This is an advantage from a reading point of view when the drawing is new. If prints are for use in the machine shop, however, it is usually found that the blue ground of the previous process does not allow so much interference from grease marks.

Dyeline printing is available in several forms as follows :

(1) Ammonia process (positive printing).
(2) " Ferazo " process (blue printing by semi-dry methods).
(3) Semi-dry developing process (positive printing).

All three methods involve exposure in the normal manner. For medium demands a non-continuous machine may be used for this purpose, wherein the drawing and printing paper are securely clamped to a glass cylinder, which may be horizontally or vertically mounted. Illumination is provided either by an arc lamp travelling the length of the cylinder in sufficient time for exposure or by mercury vapour discharge lamps.

For the ammonia process the exposed paper is either placed in the upper division of a divided box which, in the lower division, contains a tray of liquid ammonia; or a continuous developing machine of special design may be used. In both cases there is no application of moisture to the exposed paper and so expansion and contraction are avoided, thereby giving a result true to the scale of the original drawing.

The "Ferazo" process involves a special developing machine of the roller and trough type. The drawing passes over a roller running in a special developing solution. The roller speed determines the amount of liquid applied to the sensitised surface of the paper. The actual quantity of moisture required to develop the print is so small that, for normal working, the print is dry on completion of trimming operations. This process gives a negative print having white lines on blue ground.

The semi-dry developing process is similar to the above. The development may be effected by simple swabbing of the paper with the developing solution or by the roller and trough machine, hand or electrically driven. The print obtained may be either of the black or brown line types, of which the former usually requires a little less exposure time, and both are of the positive reproduction type.

Either of these processes, using continuous developing machines, may be relied upon to give up to 100 full-size prints per day from one experienced operative.

Positive printing methods appear to be most popular to-day, as some 75 per cent. of photopaper consumption is by one or other of the positive processes, i.e. ammonia or semi-dry.

"Photostat" Methods.—This is essentially a photographic method. The original drawing is clamped to a floodlit mounting board, and a special camera reproduces an image of it on to a section of a roll of sensitised paper contained by the apparatus. On exposure being completed the section of paper is rolled off into a self-contained developing bath and, on development time elapsing, drawn into the open "hypo" or fixing bath, wherein it arrives face downwards. After a few minutes it may be inverted to examine results before final washing.

A few of the advantages of this method are listed here:

(1) Change of scale to fixed proportions may be simply achieved for definite settings of lens. Intermediate scale changes are obtained by pre-focusing on to a ground-glass screen.

(2) Reproductions may be directly made from prints or from any printed matter which is non-transparent or transparent.

(3) Transparent film negatives may be produced by means of a simple conversion. This permits the use of the "photostat" as a means of reproducing reduced negatives for filing. These may be used for reproduction purposes by any of the normal dyeline or blue-print methods.

(4) The resultant print is well suited to withstand the effects of oil and grease in the shops.

(5) All colours reproduce to visual values in monochromatic form, and prints may be made permanent by washing for thirty minutes.

(6) Prints are not damaged by folding, will not fade, cannot be erased and will take pencil, ink or colour.

The print obtained is negative as in the case of the blue printing. If a positive print is required the original is replaced by the print first obtained and the process repeated as often as desired.

Normal Photographic Methods.—See "Filing of Drawings" for method of making master copies from original drawings.

When prints are required from the master copy the filed negative is withdrawn and enlarged to the required size and issued to the Work's Print File as for normal print routine.

Reproduction on Metal, Wood, Plastics, and Cloth.—For many years it has been the practice that, on receipt of drawings in the workshops, these must be copied on to the metal by individual marking out by hand. Where quantity production is involved, the shops make up accurate contour and drilling templates from the instructions on the drawing, in order to save the time of marking out individual pieces. Even so, considerable time is spent in some industries on the manufacture of these templates, of which many thousands may be required for a particular model.

Much of this time may now be saved by the photographic production of templates by new processes recently evolved. These, it is claimed by the aircraft industry, may save as much as £5,000 per model and reduce the time between design and test flight by from two to four months.

The processes described here involve coating the component with a light-sensitive emulsion, and by a variety of ways reproducing accurate drawings by normal photographic methods. The emulsion must, of course, have good properties of adhesion to the component, resistance to flaking on machining operations being performed, and reproductive accuracy of the original drawing, which in turn must be drawn and remain accurately to scale.

Where a high degree of accuracy is not required, the drawing may be prepared on tracing cloth or tracing paper, but where the stretching limits of these materials are in excess of permissible changes, the drawings are prepared on glass, white-coated metal, or on any of the translucent plastic drawing materials now available.

The P.A.C. Metasit Process.—This process has been developed with a view to achieving maximum simplicity of operation and maximum accuracy of reproduction. Two types of emulsion are available: one of high speed necessitating processing in a dark-room; the other of low speed, which can be handled in normal printing-room illumination intensities.

The base of the low-speed (Type DL) emulsion is formed by a lacquer which can be sprayed, brushed, or poured on the metal to be sensitised, and drying time is a matter of minutes. Certain metals, and materials such as wood, cloth, etc., may require a substratum to render them suitable for adhesion of the emulsion.

Exposure is effected in a clamp-type printing frame by arc or mercury vapour light, and is of some three to four minutes' duration at 3 ft. 6 in. distance. Development is simply carried out by swabbing with a special solution or, for large surfaces, by spray gun. The image appears immediately and the work-piece dries in a few seconds. No further fixing or washing processes are required, and the reproduction is permanent to light and will withstand considerable wear and tear. No varnishing is required to prevent flaking or absorption of humidity from the atmosphere. Reproduction accuracy is as high as approximately 0·001 in. per foot, so that in this respect the coefficients of expansion of both work-piece and original may be balanced to achieve fullest benefit from the reproductive accuracy of the emulsion.

The high-speed emulsion (Type HS) is a concentrated silver-bromide photographic emulsion, which is sprayed on to the work-piece to be treated. Exposure may be by contact or projection printing, and processing is by normal photographic methods. A strong contrast control and anti-fogging developer is recommended for development of the exposed image, followed by rinsing in water, fixing in an acid hardening fixing bath, and normal washing and drying processes. The results are again permanent and able to withstand wear, but where weathering is encountered, lacquering with a transparent lacquer is recommended.

The "Kodak" Transfer Sensitising Process.*—This process depends upon transforming a light-sensitive emulsion from the paper backing on which it is supplied to the lacquered surface of the work-piece. All processes, after lacquering, are carried out in the dark-room.

The surface to receive the reproduction is lacquered either by spray or brush and allowed to dry. White lacquer is used for dark surfaces, clear lacquer for light surfaces such as aluminium. Wood and other porous materials are first treated with a cellulose primer to seal pores, and metal may require degreasing. Normally one coat of lacquer will prove satisfactory, but where two coats are necessary an intermediate drying time of at least six hours should be allowed. Twenty-four hours should elapse between lacquering and sensitising the surface, although a few hours will suffice if time is important.

The sensitising paper is cut roughly to size, allowing a few extra inches at one end, placed face downwards on the lacquered surface, and the length turned back over a rubber roller positioned on the extended end of the paper. A film of softener is applied to the whole surface of the lacquer, and in a few seconds the paper rolled down on to the tacky lacquered surface of the work-piece. Projecting edges are now trimmed off and the metal with sensitised paper set aside

* See Kodak Data Sheets D2 and X41.

to dry for a few hours. The paper backing is then stripped off the surface, pulling at an acute angle, and the treated surface, retaining the emulsion film of the paper, is now ready for exposure. This may be effected in a variety of ways:

(1) The drawing is direct contact printed on to the metal as follows:

(*a*) By normal contact exposure through transparent original.

(*b*) By a special method employing X-rays. Here the original may be completely opaque, being executed on a white lacquered surface which contains material which fluoresces in the presence of X-rays. Exposure in this case is either through the back of the original plate, using X-rays, or by using the afterglow from the fluorescent material.

(*c*) By a reflex transfer technique in which the transfer-sensitive paper is clamped to the opaque original and exposed *through* the paper. (About ten seconds at 4 ft. distance using 100-watt pearl bulb in white reflector.) The exposed sheet is then laminated to the work-piece as previously described. If the two operations, exposure and laminating, are performed in fairly quick succession, dimensional accuracy on reproduction is usually approximately 0·003 in. per foot or better.

(2) The drawing is reproduced on to a negative which is again transferred to the work-piece.

(*a*) A reflex copy is produced on a glass reflex plate and this contact printed as in (1) (*a*).

(*b*) Either methods (1) (*a*) or (1) (*b*) may be used to produce the negative on to a glass plate which, in turn, is reproduced on the work-piece.

(3) A negative is made by camera methods which is transferred to the work-piece with or without magnification change. Specially made equipment is essential if this method is to prove accurate. The Lockheed Aircraft Corporation uses a camera 34 ft. long with a Cooke f12·5 lens of 19 in. focal length and a projector equipped with a 70-in. focal-length lens. The maximum error now allowed is limited to 0·001 in. per foot.

The exposed work-piece is developed by a non-caustic developer. Where reaction is liable to take place between developing solution and work-piece, the latter is lacquered, one coat, on back and edges as well as on front. Transfer-sensitised plywood may be treated in the same manner, or developer may be applied by means of swabs. For small-size work normal dish or tank equipment may be used, but where large sheets are involved it may be necessary to install large dishes, or deep tanks with overhead gantry gear may be required so that several sheets may be processed together.

Special Features.—By producing various lines of the drawing in different colours only selected parts are reproduced. Panchromatic plates are used in this process and the drawing photographed through selected colour filters, each exposure eliminating or retaining any particular group of lines.

Another method of achieving the foregoing result is that of making a glass negative of an ink or pencil drawing. This is then printed on transfer-sensitised metal in the normal manner and, by an additional processing step, all black silver lines changed to blue. On inking in the selected line with black ink and rephotographing on a blue-sensitive plate, the white background and blue lines reproduce to almost the same density. The black inked line, with any added detail, is therefore shown alone. Similar results are obtained by drawing the original in blue and black lines, retaining the use of black for those parts to be reproduced.

Symmetrical drawings may be prepared by showing only the portion to be repeated. Where the drawing is symmetrical about a common datum line, one-half only is drawn and two reduced negatives made from this. These are placed face to face in contact on the common datum and the combined image projected on to the sensitised metal as before.

When modifications are necessary these may be effected in the following ways:

(1) Modify original drawing and rephotograph.

(2) If modification is local it may be drawn on a separate sheet and photographically inserted in existing copies by resensitising areas affected. White lacquer is used if existing lines are to be obscured and clear if they are to be retained.

PATENTS, DESIGNS, AND TRADE MARKS

Important Note regarding War Conditions.—The time-limits and other conditions and requirements given in the following particulars may be modified or extended under the Patents, Designs, Copyright and Trade Marks (Emergency) Act, 1939, which came into operation from the 3 September 1939. Under this Act the Comptroller has wide power to extend time-limits having regard to war circumstances (e.g. extending time for filing complete specifications, payment of overdue taxes, and taking other steps within the time-limits defined by the Acts), and to grant, revoke, or vary licences under Patents, Designs, or Copyright and to suspend Trade Marks of enemy subjects.

Patents

Letters Patents for inventions are monopolies granted by the Crown for a limited term of years (about sixteen) to patentees to make, use, exercise, and vend within the United Kingdom of Great Britain and Northern Ireland and the Isle of Man new and useful inventions.

A patentable invention must be for " a manner of new manufacture." It must contain subject-matter or invention, have greater utility than that already known, and not have been made, used, or known or patented within fifty years before the date of applying for a patent.

Applicant for Patent.—Any person, who is the true and first inventor, may apply alone or jointly with one or more persons, company, or other corporate body. Any person, company, or corporate body can apply for a patent as communicatee of an invention emanating from an inventor residing abroad or under the terms of the International and Colonial Arrangements.

The legal representative of a deceased inventor may also apply for a patent for the invention of said inventor.

Employer and Employee.—The invention of an employee, even if carried out in the employer's time and with his materials, is the property of the employee, subject to any agreement to the contrary. But if an employee is specifically engaged to work out the details of an invention or carry it into practice, then any suggestion or invention emanating from the employee during such work is the property of the employer.

An Application for Patent must be accompanied by either a provisional specification or a complete specification, and must be restricted to one invention.

An application for patent (Patents Form No. 1) must be signed by the inventor, either alone or jointly with one or more persons, or on behalf of a company or other corporate body.

For an application for patent communicated from abroad, Form No. 1A must be used. In each case the form must be impressed with a £1 stamp.

Where the Admiralty, Secretary of State for War, or Secretary of State for Air has certified to the Comptroller that particulars of an invention should be kept secret, the application for patent must be made on Form 1D.

An Application for Patent under International and Colonial arrangements, whereby the priority date of the first patent application filed for the same invention in a country which has a corresponding reciprocal arrangement with this country may be claimed, must be filed in this country within twelve months from the date of the first patent application in such a country and must be made on either Form 1B or Form 1B*, or Form 1C* or Form 1C*† ; a £1 impressed stamp is required on each said Form.

Publication of Invention before applying for Patent.—An invention may be published by the reading of a paper before a learned society or by being shown at an exhibition, certified by the Board of Trade, without affecting the validity of any patent subsequently granted for the invention provided application is made to the Comptroller on Form 38, stamped £1, and a patent application for the invention is filed within six months from said publication.

Divided Patent Application.—If an application for patent covers more than one invention, the Comptroller may call for division, in which case the excised

invention may form the basis of a fresh application bearing the same date as the original application.

Post-dating Patent Applications.—If new matter is introduced into a patent application, either in the complete specification or by amendment during its prosecution, the Comptroller may either call for its excision or post-date the application to the date when such new matter was introduced.

The applicant may, before the acceptance of the complete specification, or within twelve or thirteen months from the date of application in the case of an application filed with a provisional specification, request the application to be post-dated not later than six months from the original date of application on filing Form 4 stamped £2 for one month ; £4 for two months ; £6 for three months ; £8 for four months ; £10 for five months ; and £12 for six months.

Amendment of Application Form.—An application form may be amended on filing Form No. 18B stamped £1 10s.

The provisional specification must describe the nature of the invention and need not necessarily make reference to a drawing. It should be prepared in duplicate on Form No. 2 (unstamped) and be filed or posted with the appropriate application form to : The Comptroller, The Patent Office, 25 Southampton Buildings, London, W.C.2. **Note.**—A provisional specification cannot be filed with a patent application made under International or Colonial arrangements ; it must be a complete specification.

Amendment of provisional specification may be effected before acceptance on filing Form 18A stamped £1 10s.

The complete specification must describe not only the nature of the invention but give detailed information as to the best means for carrying the invention into practice, and if capable of being illustrated must be accompanied with drawings to which specific reference must be made in the specification.

The specification must end with a distinct statement of claim setting forth clearly the invention claimed for which a patent is sought. Claims should not be for the efficiency or advantages of the invention. The complete specification must be prepared in duplicate on Form No. 3, and one copy must bear an impressed stamp for £4 and be filed or posted to the Patent Office.

If a complete specification be not lodged at the Patent Office in the first instance with Application Form Nos. 1 or 1A (it is, however, obligatory with Forms 1B or 1B* as above stated), and a full patent is desired, then a complete specification must be filed within twelve months from the date of the patent application or within thirteen months ; in the latter case an extension of time for one month (the longest extension obtainable) must be applied for on Form No. 6, bearing an impressed stamp for £2.

Amendment of a complete specification may be effected before its acceptance by filing Form 18A, stamped £1 10s.

Cognate Inventions.—Where the same applicant has two or more pending provisional specifications for inventions which are modifications one of the other and has obtained thereby concurrent provisional protection for same, then such pending provisional applications may be included in a single complete specification.

Chemical Products and Substances for Food or Medicine.—In the case of such inventions the complete specification shall not include claims for the substance itself except when prepared by a particular method, i.e. not a mere admixture of known ingredients.

Drawings for patent applications must be prepared with black ink (indian ink) on good-quality smooth-surfaced drawing paper measuring thirteen inches in length and eight or eight and a quarter inches in width, and be accompanied with a true copy on paper or tracing cloth, on which copy the reference letters or numerals must be in pencil (black lead) and not ink. As many sheets may be used as is necessary to fully illustrate the invention. **Note.**—In the case of patent application under International and Colonial arrangements, two true copies of the drawings are required.

Official Search for Novelty.—After the complete specification has been filed, and not before, is made the official search for novelty of the invention before the complete specification is accepted.

After the result of such search is communicated to the applicant, the complete

specification must be amended within two months to overcome the prior citations, if any, and to overcome any objections raised by the examiner. An extension of time for amending the specification to overcome prior citations may be obtained by filing Form No. 7 impressed with a stamp of 10s. for each month's extension required.

If, after amendment of the complete specification and after a hearing before the Comptroller, he is satisfied that the invention claimed is still partly anticipated, he may insert references to prior specifications, or if wholly anticipated may refuse to accept the specification.

The Comptroller has also power to refuse an application for a frivolous invention or one contrary to natural laws or one the use of which would be contrary to law or morality.

A complete specification, in normal cases, must be accepted within eighteen months from the date of the patent application, but this period may be extended up to twenty-one months. Application for extension of time must be made on Form No. 8 or No. 8A—impressed with a stamp for £2 for one month's extension; £4 for two months: and £6 for three months.

In chemical inventions, the Comptroller may require typical samples and specimens to be furnished before the complete specification is accepted.

Result of Official Search.—After a complete specification has been accepted any person may make application on Form No. 9 stamped £1, to be informed of the result of the official search made in connection with such specification.

Amendment of complete specification (including drawings) after acceptance by way of disclaimer, correction, or explanation may be made by the applicant on filing Form No. 18, stamped £1 10s. Opposition to amendment may be made on Form No. 19, and notification to attend hearing before the Comptroller in such proceedings must be made on Form No. 11, stamped £2.

Printed specifications are obtainable, price 1s. per copy, from the Sales Branch, The Patent Office.

Opposition to the grant of a patent on various specified grounds, such as fraud, ambiguity, prior publication, must be made on Form No. 10 bearing a £1 stamp and filed at the Patent Office within two months from the date of the advertisement in *The Official Journal* (*Patents*) of the acceptance of the complete specification. When an extension of time for filing opposition is desired, application must be made on Form No. 10A, stamped £1, and filed before the expiry of the normal period of two months. Attendance at hearing before the Comptroller must be notified on Form No. 11, stamped £2.

The actual deviser of the whole or a substantial part of an invention may be mentioned in a patent without conferring any rights under the patent, provided application is made not later than two months after the date of the advertisement of the acceptance of the complete specification or within an extension of one month. Provision is also made for contesting the applicant's claim to be so mentioned and to annul such mention after having been made. Forms 11A or 11B or 11C, each bearing a stamp for 10s., or Form 11D, stamped £1, must be filed as appropriate to the occasion.

Grant of Patent.—After the complete specification has been accepted, a patent is sealed on payment of the sealing fee on Form No. 12, stamped £1. In normal cases a patent must be sealed within twenty-one months from the date of the patent application. An extension of time for sealing a patent may be obtained on filing Form No. 13, bearing an impressed stamp for £2 for one month's extension; £4 for two months; and £6 for three months. In certain exceptional cases the period may be further extended on filing Form No. 13A, bearing an impressed stamp for £2 for each month's extension applied for.

Grant of Patent to Assignee.—Before the sealing of a patent on filing, Form 1E, stamped £1, the assignee of an invention may be granted the patent in his name.

Where an applicant in a joint patent application has died, the patent may be granted to the survivor or survivors.

In the case of disputes between joint applicants as to proceeding with a patent application, the Comptroller may allow one or more of the applicants to proceed and grant the patent to him or them.

Provisional protection is the period between the date of the patent application and the sealing of the patent. There is no such thing as a **provisional patent.**

Joint patentees, unless specified to the contrary, are joint tenants, and if one of the parties dies his beneficial interest becomes part of his personal estate. Each patentee can use the invention for his own profit without accounting to the others, but shall not be entitled to grant a licence without their consent. But this may be varied on making application to the Comptroller on Form No. 40, stamped with a £5 stamp.

Duplicate Patent.—If a patent is lost or destroyed a duplicate patent may be issued on filing Form No. 37, stamped £2.

Register of Patents is kept at the Patent Office wherein are entered names and addresses of grantees of patents, notifications of assignments, licences, amendments, extensions, and revocations, and all other matters relating to the validity or proprietorship of patents. The fee for inspecting the Register, original documents, samples or specimens is 1s. A request for alteration of a name or address and an address for service is made on Form No. 30, stamped 5s. A request for entry of two addresses for service is made on Form No. 31, stamped 5s.

"Licences of Right."—A patent (after sealing) may be endorsed "Licences of Right" by filing Form No. 20, stamped £1. Patents so endorsed are subject to the grant of a licence to any person making due application therefor, and thereafter only half the usual taxes are payable to keep the patent in force. Objection to such endorsement may be made on Form No. 21, stamped £2. An application for settlement of the terms of a licence must be made on Form No. 22, stamped with a £5 stamp.

The cancellation of an endorsement may be made by a patentee on filing Form No. 23, stamped £2, and opposition to such cancellation on Form No. 24, stamped £2. Attendance at a hearing before the Comptroller in above opposition proceedings must be notified on Form No. 11, stamped £2.

Duration of Patent.—The term of a patent is sixteen years from its date, i.e. date of application, but on patents granted after August 1938 the duration is for a term beginning at the date of the patent and ending at the expiration of sixteen years from the date of leaving the complete specification. The duration of a patent may be extended up to a further period of ten years beyond its normal life by petition to the Supreme Court.

Taxes are payable to keep a patent in force annually after the fourth year from its date by filing Form No. 14 having an impressed stamp for £5 in respect of the fifth year, £6 in respect of the sixth year, and so on, increasing £1 each year until £16 is payable for the remainder of the term.

Extension of time for payment of taxes up to three months may be obtained on filing Form No. 15, stamped with £2 for one month's extension, £4 for two months, and £6 for three months.

In exceptional cases when a patent has been allowed to lapse unintentionally the Comptroller has power to reinstate it on filing Form No. 16, bearing a £20 stamp. Opposition to the reinstatement of a lapsed patent may be made on Form No. 17, stamped £1.

Patents of Addition are granted for any improvement in or modification of an invention forming the subject of a patent application, a patent or a patent of addition. No taxes are payable on patents of addition so long as the original patent is in force, but only become payable in the event of the original patent being revoked, in which case the patent of addition becomes an independent patent. Application for a patent of addition must be made either on Form No. 1c, Form No. 1c*, Form No. 1c**, Form No. 1c*†, or Form No. 1c***, each stamped £1.

Application for the grant of a patent of addition in lieu of an independent patent must be made on Form No. 13B, stamped £5.

Fraudulent Patent Application.—Where a patent has been obtained in fraud of the true inventor and has been revoked or the grant of a patent has been refused, a patent may be granted for the invention to the true inventor on his making application therefor and be dated as that of the fraudulent patent or patent application.

Publication or use of the invention subsequent to the fraudulent application will not invalidate the patent subsequently granted to the true inventor.

Correction of Clerical Errors.—A request for the correction of a clerical error in the documents of a Patent Application must be made on Form No. 35, stamped 10s. If the correction is required in the documents after a patent has been sealed or in any matter entered on the Register of Patents, the Form 35 must be stamped £1.

Notice of opposition to the correction of a clerical error must be made on Form No. 35A, stamped £1. Notification to attend hearing before the Comptroller in such proceedings must be made on Form No. 11, stamped £2.

Amendment of specification (including drawings) by way of disclaimer, correction, or explanation may be made at any time by the patentee on Form No. 18, stamped with a £3 stamp. Opposition to amendment must be made on Form No. 19, stamped £1, and notification to attend hearing before the Comptroller in such proceedings must be made on Form No. 11, stamped £2.

Abuse of Monopoly of Rights.—Any person after the expiration of three years from the date of sealing a patent can apply on Form No. 27, stamped with £5 stamp, alleging abuse of monopoly rights and apply for the grant of a compulsory licence or revocation of the patent. If a hearing before the Comptroller is desired, Form No. 28 must be filed, stamped with a £2 stamp. Monopoly rights are deemed to be abused: Firstly, if the invention (being one capable of being worked in the United Kingdom) is not worked commercially within three years from sealing the patent and no satisfactory reason can be given for such non-working; secondly, if the working within the United Kingdom is prevented or hindered by importation from abroad of the patented article; thirdly, if the demand for the patented article is not met to an adequate extent on reasonable terms; fourthly, if by the refusal of the patentee to grant a licence upon reasonable terms, trade is prejudicially affected; fifthly, if any person or trade is unfairly prejudiced by conditions imposed by the patentee on the purchase, hire, or use of the patented article; and sixthly, if it is shown that the existence of the patent, being a patent for a process involving the use of materials not protected by the patent or for a substance produced by such a process, has been used by the patentee to unfairly prejudice in the United Kingdom the manufacture, use, or sale of any such materials.

Assignments, licences and other documents affecting the proprietorship of patents must be entered on the Register of Patents. Application for entry of proprietor or part proprietor must be made on Form No. 32, for a mortgage or licence on Form No. 33, and a notification of a document on Form No. 34. Form 32 must be stamped £1 in respect of one patent if application be made within six months from date of acquisition of proprietorship; £2 10s. if made within twelve months; and £3 if made after twelve months, and 2s. 6d. for each additional patent included in one deed. Forms 33 and 34 must each be stamped £1 if filed within six months from date of document, acquisition of interest or sealing of the patent whichever is the later and bear a stamp for £2 10s. if made after six months but within twelve months and £3 after twelve months plus 2s. 6d. for each additional patent included in the same document.

Licences under patents for food or medicine must be applied for on Form No. 29, bearing a stamp for £5.

Revocation of a Patent may be obtained on petition to the Court or within twelve months from the date of sealing a patent on making application to the Comptroller on Form No. 25, stamped £2. Notification to attend hearing before Comptroller in such a proceeding must be made on Form No. 11, stamped £2. An offer to surrender the patent after such proceedings have commenced must be made on Form No. 26, stamped £1. Opposition to the surrender of the patent may be made on Form No. 26A, stamped £1, and must be filed within one month of the date of the first advertisement of the surrender offer. Notification to attend hearing before the Comptroller in such opposition proceedings must be made on Form No. 11, stamped £2.

Appeals from the decisions of the Comptroller are made to an "Appeal Tribunal" consisting of a judge of the High Court.

Certificate of Comptroller.—A request for a certificate of the Comptroller as to any entry or matter which he is authorised to make by the Acts or Rules must be made on Form No. 36, stamped 10s.

Information respecting a patent or patent application must be made on Form No. 36A, stamped 10s.

Infringement of Patent.—No action for infringement of a patent can be commenced until a patent is actually sealed, and only damages can be claimed for infringement committed after the acceptance of the complete specification. A patentee may obtain an injunction to restrain infringement, but cannot recover any damages in respect of infringement if the infringer proves that he was not aware of the existence of the patent. Marking an article with the words " Patent " or " Patented " is not notice of the existence of a patent unless the number of the patent is given.

The plaintiff in an infringement action is entitled to relief by way of injunction and damages but not to an account of profits.

One or more invalid claims in a specification are not sufficient to invalidate a patent in an infringement action provided that the invalid claim was framed in good faith and with reasonable skill and knowledge.

Groundless threats of legal proceedings for infringement of a patent may be restrained and damages recovered.

Crown.—A patent has the like effect as against His Majesty the King as it has against a subject, but any Government Department or their authorised agents can make use of, or exercise the invention for the services of the Crown.

Offences.—It is not lawful for a patentee to prohibit or restrict a purchaser or licensee from using any article, patented or not, supplied by any person other than the patentee or to make it necessary to acquire from the patentee any article not protected by the patent.

It is a misdemeanour to make any false entry in the Register of Patents. Any person falsely representing an article to be a patented article is liable on conviction to a fine not exceeding £5 for every offence.

The grant of a patent does not authorise the patentee to use the Royal Arms. Unauthorised use of the Royal Arms carries a penalty up to £20 on conviction.

The use of the words " Patent Office " or a similar designation on business premises, letter paper, or other documents renders the user liable on conviction to a fine not exceeding £20.

Any person practising as a Patent Agent unless registered commits an offence punishable on conviction to a fine not exceeding £20 for the first offence, and on subsequent conviction to a fine not exceeding £50.

Patent Agents.—All business with the Patent Office, including the signing of many of the necessary documents, may be transacted through a registered Patent Agent, who must be a British subject, and duly authorised to the satisfaction of the Comptroller of Patents.

A list of registered Patent Agents may be obtained (price 6d.) from the Chartered Institute of Patent Agents, Staple Inn Buildings, London, W.C.1, or through any bookseller.

Designs

A registrable Design under the Patents and Designs Acts, 1907–1942, concerns only the shape, configuration, pattern, or ornament of an article and is judged solely by the eye. It does not cover any principle of construction or any mechanism, and utility is not an essential feature, but it must not have been previously published in the United Kingdom. **Note.**—Section 22 of the Copyright Act, 1911, does not give protection for a design when it is reproduced or intended to be reproduced in more than fifty single articles unless all the articles together form a single " set " or where the design is applied to printed paper hangings or to carpets or floor coverings made or sold in lengths or pieces or to textile piece goods or to lace not made by hand.

Applicants for Registration.—Any person or persons (not necessarily including the author or designer), a firm, company, or body corporate, who is or are the proprietor or proprietors of a new and original design, may apply for registration.

Classification of Goods.—For the purpose of registration, articles or goods are classified into fifteen groups according to the materials of which they are composed.

Application for registration must be signed by the applicant or applicants or by a duly appointed agent (Designs Form No. 1).

For articles of metal (class 1); books and bookbinding materials (class 2); articles of wood or other solid substances (class 3); glass, china, and earthenware articles (class 4); paper (except books and paper hangings) (class 5); leather (class 6); paper hangings (class 7); carpets and floor coverings (class 8); boots and shoes (class 10); wearing apparel (except boots and shoes) (class 11); and goods not included in other classes (class 12); applications must be made on Designs Form No. 2, stamped with a 10s. stamp and accompanied by three identical representations or specimens of the design.

International or Inter-Imperial Arrangements.—For an application for a design registration in any one of the above classes under International or Inter-Imperial arrangements whereby the priority date of the first design registration filed for the same design in a country which has a corresponding reciprocal arrangement with this country may be claimed; the application must be filed within six months of the first application in such country and must be made on Designs Form No. 2A, also stamped with a 10s. stamp and accompanied by three identical representations or specimens of the design. The application form and representations in each case must be filed or posted to the Comptroller, The Patent Office (Designs Branch), 25 Southampton Buildings, London, W.C.2.

" Set " of Designs.—Application for registration of a number of articles of the same general character ordinarily on sale or intended to be used together must be made on Designs Form No. 3 and stamped with £1 stamp and accompanied with four representations or specimens. If application be made under International and Inter-Imperial arrangements, Designs Form No. 3A must be used, also stamped £1 and accompanied with four representations or specimens.

Lace Designs (class 9).—Application must be made on Designs Form No. 4 and stamped 2s. 6d. and accompanied by three representations or specimens of the design. If for a " set," application is to be made on Designs Form No. 5, stamped 5s. and accompanied with four representations or specimens.

Applications for printed or woven designs on textile piece goods (class 13), on handkerchiefs and shawls (class 14), must be made on Designs Form (Manchester) No. 1, stamped 5s. For checks or stripes either on piece goods or handkerchiefs (class 15), application must be made on Designs Form (Manchester) No. 2, stamped 2s. 6d. Each form must be accompanied by an unstamped duplicate together with four identical representations or specimens and be filed or posted either to the Comptroller, The Patent Office (Designs Branch), or to the Keeper of Cotton Marks, 51 Regent House, Cannon Street, Manchester, 4.

Publication of an Unregistered Design.—A design may be published by being shown at an exhibition, certified by the Board of Trade, without invalidating a subsequent registration provided application is made to the Comptroller on Designs Form No. 26, stamped 5s., and an application for registration is made within six months from date of opening of said exhibition.

Registration of Design in more than one Class.—Where a design has been registered in one or more classes the proprietor of the design may subsequently register the same design in one or more other classes, but the term of copyright in such subsequent registration will not extend beyond the term of the original registration.

Extension of Time for Completion of Application.—If an application for registration is not completed within twelve months from date of application by default of the applicant, it becomes abandoned. However, an extension of time up to three months may be obtained by filing Designs Form No. 8, stamped 10s. for one month's extension; £1 for two months; and £1 10s. or three months.

Refusal of Registration by Comptroller.—If after a hearing before the Comptroller, the application for registration is refused and the applicant desires to appeal to the Appeal Tribunal, he must apply on Designs Form No. 7, stamped 10s., within one month from such hearing, and the date when the Comptroller complies with such form is the date of the decision for the purpose of an appeal.

Duration of copyright is five years from date of application for registration, which term may be extended for a further period of five years on filing Designs Form No. 9, stamped £2, within the first period; and an extension for a further period of five years, making fifteen years in all, may be obtained on filing Designs Form No. 10, stamped £5, within the second period. If an extension of time, up to three months, is required to pay either fee, then Designs Form No. 11, stamped 10s. for one month's extension, £1 for two months, and £1 10s. for three months, must be filed. The fees for the full term of fifteen years may be paid in advance.

Marking of Goods.—Before delivery on sale of any goods to which a registered design has been applied, the proprietor of such design must mark each article with the word "Registered," "Regd.," or "Rd.," together (except in the case of articles in classes 9, 13, 14, and 15) with the number appearing on the certificate of registration.

Such marking is dispensed with in the case of printed or woven textile goods other than handkerchiefs.

If articles are not so marked where requisite, the proprietor of the design is not entitled to recover any penalty or damages for infringement of his copyright unless he proves that all necessary steps were taken to ensure the marking or unless he shows that infringement took place after the infringer had received notice of the existence of the copyright.

Duplicate of Certificate of Registration.—If the original certificate of registration be lost or destroyed, a duplicate may be issued on filing Designs Form No. 28, stamped 10s.

Register of Designs is kept at the Patent Office wherein is entered the names and address of proprietors, notifications of assignments, and transmission of registered designs and other matters relating thereto. The fee for inspecting the Register or a registered design is 1s.

Manchester Register.—Registration of designs in classes 13, 14, and 15 and matters in connection therewith are entered on the Manchester Register which is kept at 51 Regent House, Cannon Street, Manchester, 4.

Where a dispute arises with reference to designs entered in the Manchester Register, the parties thereto may give notice in duplicate on Designs Form (Manchester) No. 3, one being stamped 5s., to the Keeper of Cotton Marks at above address.

Correction of Errors in an application for registration, representation, or Register may be made by filing Designs Form No. 18, stamped 10s.

Assignments, mortgages, or licences and notifications must be entered on the Register. A joint request by a registered proprietor, mortgagee, or licensee must be made on Designs Form No. 12; a request to enter names of subsequent proprietor, mortgagee, or licensee must be made on Designs Form No. 13, and a request for the notification of a document must be made on Designs Form No. 14. Each said form must be stamped 10s. for one design plus 2s. 6d. for each additional design if made within six months from date of acquisition of proprietorship, etc.; or stamped £2 10s. for one design plus 2s. 6d. for each additional design if made after six months and within twelve months of acquisition, etc.; or stamped £3 for one design plus 2s. 6d. for each additional design if made after twelve months from acquisition, etc.

Application by a mortgagee or licensee for removal of his name from the Register must be made on Designs Form No. 15, stamped 10s. for one design plus 2s. 6d. for each additional design.

The alteration of a change of name of the registered proprietor must be made on Designs Form No. 16, stamped 10s. for one design plus 2s. 6d. for each additional design.

The alteration of a change of address or an address for service must be made on Designs Form No. 17, stamped 5s. for one design plus 1s. for each additional design.

Application by registered proprietor to cancel entry in Register must be made on Designs Form No. 19, stamped 5s.

Infringement of a Registered Design.—Any person infringing the copyright in a registered design either by applying the design to any article or exposing the infringing article for sale is liable for every contravention to pay the proprietor

a sum not exceeding £50 recoverable as a simple contract debt provided that the total sum in respect of any one design shall not exceed £100.

The proprietor may elect to bring an action for the infringement and for an injunction against repetition and may be awarded damages and an injunction.

Information Respecting a Registered Design.—Any person may apply for information respecting a registered design, e.g. if in force, classes of goods covered, date of registration, and name and address of registered proprietor. If the number of the design registration is known, application is made on Designs Form No. 20, stamped 5s., or if unknown on Designs Form No. 21, stamped 10s.

Search amongst Registered Designs.—The Comptroller may make a search to ascertain if any proposed design is covered in any existing design by filing Designs Form No. 22, stamped 10s.

Certificate of Comptroller.—A request for a certificate for use in legal proceedings or for other special purpose may be applied for on Designs Form No. 23, stamped 10s.

Cancellation of a Registered Design or Grant of a Compulsory Licence.—An application for cancellation of a registered design on the ground that it was published in the United Kingdom prior to the date of registration, or for the grant of a compulsory licence on the ground that the demand for the registered article is met by importation, must be made on Designs Form No. 24, stamped £2. Notification that a hearing before the Comptroller in the matter will be attended must be made on Designs Form No. 25, stamped £1.

An entry of order of the Court in Register must be made on Designs Form No. 27, stamped 10s.

Crown.—The registration of a design has the like effect as against His Majesty the King as it has against a subject, but any Government Department or their authorised agents can enjoy the copyright for the services of the Crown.

Offences.—It is a misdemeanour to make any false entry in the Register of Designs.

Any person falsely representing an article to be the subject of a registered design or who applies the word "Registered" or any other word implying that the article is the subject of a registered design or applies the word "Registered" (or similar words or contractions) to an article in which the copyright has expired shall be liable on conviction under the Summary Jurisdiction Acts to a fine not exceeding £5.

Trade Marks

A trade mark is a device, brand, heading, label, ticket, name, signature, word, letter, numeral, or any combination thereof.

A registered trade mark is a trade mark that is actually on the Register of trade marks.

The Register of trade marks is kept at the Patent Office and is a record of all registered trade marks and all matters pertaining thereto. It is divided into two parts, Part A and Part B. The fee for inspecting the Register or documents in relation to registration is 1s. for each quarter of an hour.

The Sheffield Register is kept by The Cutlers' Company in Sheffield, and contains particulars of and in relation to all marks for "metal" goods.

The Manchester Branch of the Register is kept at 51 Regent House, Cannon Street, Manchester 4, and contains a record and particulars of all marks with respect to "textile" goods.

Alteration of address on Register must be made on T.M. Form No. 18, stamped 10s. for first entry and 2s. for every other entry, but no fee is payable if address is changed by a public authority.

Change of name or description of proprietor or user must be requested on T.M. Form No. 21, stamped 10s. for the first mark and 2s. for every other mark.

Cancellation or amendment of entry on Register must be made either on T.N. Forms No. 22, 23, or 24, each bearing a 10s. stamp.

Unregistrable Features in Trade Marks.—The following may not appear on trade marks sought to be registered: Representations of their Majesties or any member of the Royal Family, the Royal or Imperial Crown, arms or crests or

Royal, Imperial, or National flags, Admiralty anchor, Royal Air Force badge, or semblances of any of the above and the words: Royal or Imperial, or Anzac, or Empire, or Dominion, or Crown, or Patent, Patented, Registered, Registered Design, Copyright, Entered at Stationers' Hall. To counterfeit this is a forgery, or words to like effect. Also Geneva and other crosses in red on the Swiss Federal Cross in white or silver on a red ground or words Red Cross or Geneva Cross.

No word which is the common or accepted name of a chemical substance is registrable as a trade mark.

Classification of Goods.—A trade mark can only be registered in respect of particular goods or classes of goods comprised in thirty-four different classes, formerly (before 27 July 1938) fifty classes. A list of the goods comprised in each class, price 5s., may be obtained from the Patent Office (Sales Branch), 25 Southampton Buildings, London, W.C.2.

Part A of the Register.—A mark to be registrable (other than a certification trade mark) in Part A must consist of or contain one of the following essentials: An invented word or words; a word or words having no direct reference to the character or quality of the goods and not being according to its ordinary signification a geographical name or a surname; the name of an individual, company, or firm represented in a particular manner; the signature of the applicant for registration or some predecessor in his business; and any other distinctive mark upon evidence of its distinctiveness.

In Part B of the Register, the mark must be capable of distinguishing the proprietor's goods from those of others.

Applicants and Applications for Registration.—Any person or persons, firm, partnership, or corporate body may apply for registration of a trade mark, either directly or through an authorised agent (on T.M. Form No. 1) on filing T.M. Form No. 2 for an application in either Part A or Part B of the Register, stamped £1, accompanied by four other representations on T.M. Form No. 4 and lodged or posted to the Registrar, The Patent Office, Trade-marks Registry, 25 Southampton Buildings, London, W.C.2. **Note.**—An application in respect of "metal" goods from a person in Hallamshire may be sent if desired to The Cutlers' Company, Cutlers' Hall, Sheffield, 7, in which case six other representations each on T.M. Form No. 4 must accompany the application form. In the case of marks for "textile goods," application in either Part A or Part B must be made on Textile Form No. 2 in duplicate, one bearing a £1 stamp and accompanied by six additional representations on T.M. Form No. 4 and filed or posted either to the Registrar at the Patent Office or to the Registrar, Manchester Branch, Trade-marks Registry, 51 Regent House, Cannon Street, Manchester, 4.

A mark may be limited in whole or in part to one or more specified colours.

International Convention for the Protection of Industrial Property.—Application for a priority date under the terms of the International Convention must be made within six months from the date of the first application for registration in a Convention country.

If an application for registration is rejected after a hearing before the Registrar, by filing T.M. Form No. 5, stamped £1, the Registrar will give his reasons in writing for his decision.

Appeals from Registrar to Board of Trade must be made on T.M. Form No. 30, stamped £2, accompanied by two copies of the decision of the Registrar.

Appeals to the Court are to be made by motion in the usual way and must be given within one month from the date of the decision appealed against.

Preliminary Advice on adoption of a new trade mark may be given by the Registrar on filing T.M. Form No. 29, stamped 5s., and accompanied by two representations of the proposed mark.

Request for search before making application for registration must be given on T.M. Form No. 28, stamped 15s. or £1 if preliminary advice as to suitability of trade mark is also required. The form must be accompanied by representations in duplicate.

Searches amongst classified trade marks may be made on payment of a fee of 1s. for every quarter of an hour.

Opposition to application for registration may be given by any person within one month from date of advertisement of the application in *The Trade Marks Journal* on filing T.M. Form No. 7 in duplicate, one form being stamped

£2. Within one month from receipt of notice of opposition the applicant for registration must file T.M. Form No. 8, stamped £1, together with an unstamped duplicate. When a hearing before the Registrar has been appointed, notification of attendance (both by applicant and opponent) must be made on T.M. Form No. 9, stamped £2.

Opposition to a certification trade mark must be made on T.M. Form No. 37, stamped £2, and counter statement in reply must be made on T.M. Form No. 38, stamped £1, accompanied by two unstamped duplicates. Notice of attendance at hearing must be made on T.M. Form No. 39, stamped £2.

Series Trade Marks.—The proprietor of several trade marks differing only in immaterial particulars may cover such marks in one registration. Application is made on T.M. Form No. 2 or Textile Form No. 2, stamped £1, accompanied by representations of each of the marks.

Defensive Trade Marks.—The registered proprietor of a trade mark for an invented word may apply for a defensive trade mark in respect of any goods which he does not actually use, but if used by another trader might indicate a connection with the goods of the registered proprietor. Application for such registration may be made on T.M. Form No. 32, stamped £3, and accompanied by four other representations on T.M. Form No. 4 : if in respect of "textile" goods, six such representations.

Certification Trade Marks are registrable in Part A of the Register in respect of goods adapted in relation to any other goods to distinguish goods certified by any person in respect of origin, material, quality, or other characteristics by filing T.M. Form No. 6, stamped £1, in respect of one class and £1 for each additional class, but not exceeding £20 for any number of classes, accompanied by two unstamped duplicates and six representations on T.M. Form No. 4.

A request for the consent of the Board of Trade to alterations governing the use of the mark must be made on T.M. Form No. 35, stamped £1 for one registration and 2s. for each other registration in the same request.

Application to the Board of Trade to expunge or vary an entry in the Register must be made on T.M. Form No. 36, stamped £3.

Advertisement of Trade Mark.—After a mark has been accepted, or in some cases before acceptance, the application is advertised in the *Trade Marks Journal*, for which purpose a printing block of the mark must be filed, except in the case of word marks in plain block type of uniform size. No block must exceed 5¼ in. broad by 7½ in. deep, and when a block exceeds 2 in. in breadth or depth 4s. must be paid for every inch or part of an inch beyond 2 in. in either direction.

Registration of Trade Mark.—After a mark has been advertised for one month in the *Trade Marks Journal* and not opposed or opposition proceedings disposed of, the mark is entered on the Register on filing T.M. Form No. 10, stamped £2, plus 5s. for each mark of a series or in the case of certification marks plus £2 for each class not exceeding £40; and for a defensive mark £3. In the case of "textile" marks this must be accompanied by an unstamped duplicate.

An address for service or alteration or cancellation thereof must be made on T.M. Form No. 33 and stamped 5s. for first entry and 1s. for every other entry, but if filed with registration fee (Form 10), it does not require stamping.

Association between Registered Marks.—Where a mark is registered as associated with any other mark on the Register, a fee of 2s. is payable for each mark associated with a newly registered mark. An application to dissolve the association must be made on T.M. Form No. 19, stamped £2. Associated marks are assignable and transmissible as a whole and not separately.

Duration of Registration.—A trade mark is registered for a period of seven years, but may be renewed for further periods of fourteen years each.

Application for renewal must be made on T.M. Form No. 11, stamped £2 plus 2s. 6d. for each mark of a series registration, and in the case of a certification trade mark £2 for each class, not exceeding a total of £40. The renewal form must be filed not more than three months before expiration of the last registration. If the renewal fee is not paid in due time, it may be paid within one month from date of notice received from the Registrar on filing stamped T.M. Form No. 11 and T.M. Form No. 12, stamped £1. Where the trade mark has been removed

from the Register for non-payment of fee, it may be restored on filing stamped T.M. Form No. 11, together with T.M. Form No. 13, stamped £2.

Cotton Marks.—Application for the continuance of a cotton mark in the collection of refused marks (entered before the 27 July 1938 and not thereafter) may be made on Cotton Form No. 6, stamped £1, for each mark in each class at each period of fourteen years after date of application, and sent to the Registrar, Trade-mark Registry, 51 Regent House, Cannon Street, Manchester, 4.

Assignment and Transmission of Registered Trade Marks.—A trade mark in respect of all or part of the goods covered by registration may be assigned together with the goodwill of a business or not.

Application for registration by proprietor and transferee jointly must be made on T.M. Form No. 15, and if by transferee alone on T.M. Form No. 16, each form stamped £2 if made within six months from the date of acquisition; £2 10s. after expiration of six months but within twelve months of date of acquisition; and £3 after twelve months from date of acquisition, plus 2s. 6d. in each case for each additional mark after the first. The registration of a corporation as a subsequent proprietor may be extended by filing T.M. Form No. 14, stamped £1 for two months' extension; £2 not exceeding four months; and £3 not exceeding six.

Correction of clerical errors or amendment of application form must be made on T.M. Form No. 20, stamped 10s.

Amendment of a Registered Mark.—Application must be made on T.M. Form No. 25, stamped £2 for one mark and £1 for each other mark, accompanied by four copies of the mark as amended or six copies in the case of a "textile" or "metal" mark. Opposition is made on T.M. Form No. 47, stamped £2.

A request for entry on the Register of a certificate of the Court with regard to the validity of a registered trade mark may be made on T.M. Form No. 49, stamped £1 for the first mark and 1s. for each other mark certified.

Rectification or Removal of a Registered Mark.—Application must be made on T.M. Form No. 26, stamped £3, and opposition to such proceeding must be made on T.M. Form No. 27, stamped £1. An order of the Court for alteration or rectification of the Register may be made on T.M. Form No. 48, stamped £1.

Certificate of the Registrar must be applied for on T.M. Form No. 31, stamped 10s. or £1 for a series of marks.

Certificate of Keeper of Manchester Branch in respect of "textile" marks must be made on Textile Form No. 5 and stamped 10s. or £1 for series of marks.

Certificate of Registrar with reference to a proposed assignment in respect of any particular goods covered in a registered mark must be made on T.M. Form No. 40, stamped £2 for one mark and 2s. for each other mark of the same proprietor included in the assignment. Application for assignment of exclusive rights to different persons in different parts of the United Kingdom must be made on T.M. Form No. 41 or T.M. Form No. 42 if the assignment was in respect of a mark registered before the 27 July 1938. Each form must be stamped £2 for the first mark and 2s. for each other mark included in the transfer. On application for advertisement of assignment of mark without goodwill, T.M. Form No. 43 must be filed, stamped £1 in respect of one mark and 2s. additional for each other mark. If additional time is required to file T.M. Form No. 43, application must be made on T.M. Form No. 44, stamped £1 for one month's extension; £2 for two months; and £3 for three months.

Reclassification of goods in respect of registrations effected before the 27 July 1938 may be effected on filing T.M. Form No. 45, stamped 5s. Opposition to such reclassification may be made on T.M. Form No. 46, stamped £2 for one mark and 2s. for each additional mark.

Non-user of a registered mark may be taken off the Register by application to the Court or to the Registrar who may refer the matter to the Court.

Registered User.—Permitted use of a registered mark may be made by a registered proprietor on T.M. Form No. 50, stamped £2, and variation of such a permitted use may be made on T.M. Form No. 51, stamped £2 for the first mark and 2s. for each additional mark. Cancellation of entry may be made on T.M. Form Nos. 52 or 53, stamped £2 for one mark and 2s. for each additional mark. Notice to intervene is made on T.M. Form No. 54, stamped 10s.

Furnaces for Steel Treatment.—The heat treatment of steel involves, at least in its principal stages, the heating of the material to the proper temperature in some type of furnace. These furnaces may be fired or heated by different means, using a fuel such as coke, coal, gas (town, blast furnace, or natural), fuel oil, or electricity. The actual form of furnace employed is governed largely by the particular treatment necessary and by the cost of operation. The cheapest furnace for a particular operation is not necessarily the least costly. A furnace may be low in cost per heat unit and expensive in ruined steel, maintenance, labour, etc. The correct standard for judgment of a furnace is, therefore, quality and cost of final product. Fuel efficiency is governed by fuel controllability to ensure adequate heat for the charge. Coal- and coke-fired furnaces in which the solid fuels are combusted on a stoker or grate are hard to control, and therefore only suitable for a small number of heat-treatment operations, e.g. those in the blacksmith's hearth, where maximum accuracy is neither essential nor attainable.

A heat-treatment furnace should provide a specific temperature remaining constant within specified limits, uniform over the entire furnace area during the complete treatment period, or, if required, graded to suit the operation. It must be reliable, easily regulated, and requiring little attention and maintenance cost. It should be brought to the requisite temperature rapidly and with ease, and the atmosphere of the furnace chamber should suit the work and be controllable, to ensure the proper surface condition of the steel after heat treatment. Lastly, it should be clean in operation and working conditions. Temperature variation should not be greater than plus or minus 5° C. where high accuracy is needed.

Liquid Baths for Steel Treatment.—For many operations in heat treatment it is not necessary to attain high temperatures, and for such work the steel may be brought to the correct temperature in a liquid-bath furnace, the liquid bath being composed of either oil, molten lead, or molten salts. Such baths are usually brought to the requisite temperature by heating a container or pot, in which the oil, lead, or salts are held, by electricity, gas, or oil burners. Liquid-bath heat treatment gives accurate control of temperature. Annealing is a characteristic heat-treatment operation that may be effectively carried out in baths of this type.

Molten-lead Baths.—Lead has a wide range of temperature (approx. 345–925° C.), and may therefore be employed for most hardening and tempering operations. It is easily oxidised, so that wastage and dross must be precluded as far as possible by suitably covering the bath surface with wood charcoal, coke, or similar material. Gas is usually employed for heating the container, which must be designed so that no sharp corners or quick alterations of cross section occur. Pots may be of cast iron, cast steel, cast alloy metal, or pressed steel. Cast steel is probably the most satisfactory. Lead adheres to the work, which should be protected by coating it with a thin film of salt or other material, such as calcimine and emulsions of lampblack in paraffin.

Salt Baths.—Salts for salt baths must not produce oxidation or decarburisation, corrosion or erosion. Three main types are used, those designed for low-temperature heat treatment, those for medium-temperature, and those for high-temperature. The first group are primarily for tempering carbon or low-alloy steels; the second for hardening, normalising, or annealing identical steels, and for the quenching of high-speed steels; the third, for hardening the high-alloy and high-speed steels. Low-temperature salts include nitrates and nitrites of the alkali metals. Sodium nitrite is frequently mixed with potassium nitrate in the proportion 44 : 56, and the mixture melts at 145° C. Alternatively it may be mixed with potassium nitrate in the proportion 48·7 : 51·3, when it melts at approximately 220° C. Low-temperature salts should not be heated above 590° C. The second mixture mentioned is the most useful all round, but if only very low temperatures are needed, a cheaper mixture may be equally satisfactory.

Medium-temperature salts are usually either chlorides or mixed chlorides and carbonates. Potassium chloride and sodium carbonate in the proportion 50 : 50 (melting-point 660° C.) are for non-ferrous metals; calcium chloride and sodium chloride in the proportion 56 : 44 are for steel, melting-point being 504° C.

Medium-temperature salts should not be heated above 900° C. A rectifying agent must be introduced into the bath to prevent decarburisation of the steel's surface. This agent may be fused borax, boracic acid, or boric oxide.

High-temperature salts are mixtures of barium chloride, borax, sodium fluoride, and silicates. These have a melting range from 870 to 1040° C. Ferro-silicon is sometimes employed as a rectifying agent in these baths to prevent soft skin or scaling. The preheating of steel is often done in the high-temperature salt bath.

All foreign bodies must be kept out of the bath. Cyanide salts should on no account come into contact with nitrates for fear of explosion. If there is any reason to suppose the bath impure, some cast-iron chips free from moisture and dirt should be introduced (approximately one-twentieth the total weight of the bath contents). Addition of chips should be made when the salts are almost at the maximum temperature for which they are designed. Vigorous stirring will lead to their chemical combination with the impurities, and the eventual sediment forming on the bottom should be removed.

Do not rush the heating designed to melt the salts, as this harms the container and is injurious to the bath uniformity. Salts must be renewed when necessary and when the bath is cold. In continuously operating salt baths, replenishment when cold is not feasible, so that care must be taken to ensure that the newly added salts are quite free from moisture, which may otherwise cause an explosion.

The larger the work the lower should be the melting-point of the salts. In no case should the melting-point be too near to the operating temperature. Pre-heating of parts designed to be treated in the salt bath is advantageous but not vital. Oil, gas, or electricity may be used as the heating medium, oil being mainly confined to the larger receptacles. Electricity is satisfactory for low and medium temperatures, but the salts must be kept away from the resistances. Gas is satisfactory.

Liquid-petroleum and Fuel-oil Furnaces.—These are principally employed in the United States, but some installations are to be found in this country. The liquid-petroleum furnaces are of two principal types, the propane and the butane. Propane ($CH_3CH_2CH_3$) is obtained from crude petroleum. Butane is a hydro-carbon akin to paraffin. In actuality there are two forms of butane, but that employed in fuel-fired furnaces is called "normal" butane ($CH_3CH_2CH_2CH_3$). It contains butylenes, as well as some propane and propylene ($CH_2CH.CH_3$).

These two gases are not swift in combustion, and as a result a lower speed of air-gas mixture may be employed through burner ports or nozzles without any danger of backfire. Moreover, forms of burner equipment with a lower manifold pressure may be employed. The benefit derived from this is the provision of a wider range of flame control between the full-on position and the almost-off.

The comparative efficiencies of the various liquid fuels are in direct ratio to the available heat of the gas, given similar conditions of furnace construction and management. The available heat of a fuel is the gross B.T.U. value less the amount of heat contained in the combustion products at the specific temperature.

Propane and butane both possess high available heat, and contain no incombustible constituents such as water or inert gases (nitrogen, carbon dioxide, etc.).

Fuel oil comprises a range of products distilled from petroleum or blends of these products with petroleum oils. They are often termed "heavy" fuels and are low in viscosity, so may be atomised and blown through a suitable burner without leaving residues or causing waste. The fuel oil is stored in tanks well above the actual furnaces. Steam-heating coils in the tanks maintain the tanks in a warm condition (27° C.). Combustion equipment comprises a propulsion fuel pump, a preheater to heat the oil until it reaches the required low viscosity, an air-supply register, atomisers of correct type, and an air current producer, usually a fan.

Atomisers may be of four types: (*a*) mechanical pressure; (*b*) centrifugal; (*c*) steam; (*d*) air. In (*a*) oil is supplied mechanically under high pressure, preheated by exhaust steam, and driven through a perforated plate. In (*b*) a cup contains the oil, and rotates at high speed, being impinged on by an air blast travelling round its periphery. Centrifugal force drives the oil towards the periphery, and the air blast dispels it in a fine mist. In (*c*) oil dribbles from a hole and a jet of steam dispels it by impact. In (*d*) air replaces steam, and the action is as with (*c*).

The atomiser often serves to provide air for admixture with the fuel oil, so as to cause combustion. Otherwise an air register must be used or the air introduced through openings in the furnace, either by natural or by forced draught. The flame in a fuel-oil furnace must never impinge directly on to the steel being treated nor on to the furnace lining.

Pyrometers and Pyrometry.—There are eight types of pyrometers, but not all of these are important to the steel treater. Those that concern him are the electrical-resistance, the thermo-electric, the radiation, the optical, and the fusion pyrometers.

Electrical-resistance pyrometers give a reading of higher accuracy than any other really practical thermometer, and are often employed to check other pyrometers. Their indicated temperatures need correction by Callendar's formula. Using the simple lineal equation $R_t = R_0(1 + at)$, where R_t and R_0 are the resistances of the wire at $t°$ and 0° C. respectively, and a is a constant for the metal used, a range of "platinum-scale temperatures" is obtained, and these have to be converted into true gas-scale temperatures by Callendar's correction formula :

$$t - p = \delta \left[\left(\frac{t}{100}\right)^2 - \frac{t}{100}\right]$$

Here, t is the true gas scale for the indicated platinum-scale temperature p and δ is a constant whose value depends only on the purity of the platinum used. For pure platinum δ has the value 1·5.

Disadvantages of the electrical-resistance pyrometer are that in some instances only the platinum-scale temperatures are shown, and the corresponding true temperatures must be had from tables or graphs. The platinum bulb is fragile, and the connecting wires must be protected from gases by a porcelain sheath inside an iron sheath. This gives a rather slow response to temperature variations. The pyrometer should not be used continuously for temperatures exceeding 700° C., and is mainly intended for standardisation purposes.

Thermo-electric pyrometers are based on Seebeck's principle that when two unlike metals are united and the point of union is heated and forms part of a closed circuit, it becomes the seat of an e.m.f. whose magnitude varies with the temperature of the heated junction. A sensitive galvanometer or millivoltmeter placed in the circuit without breaking it enables the magnitude of the e.m.f. to be ascertained at a number of accurately known fixed points, and so establishes a relation between temperature and e.m.f. The e.m.f. set up in a thermo-electric circuit of this type is proportional to the *difference* in temperature between the hot and cold junctions. Metals for these thermocouples are either "rare" (e.g. platinum, rhodium, or iridium) or "base" (e.g. iron, copper, nickel, etc.).

In selecting a thermocouple, maximum temperature to be measured, liability to oxidation, effect of gases, must all be considered. Rare metals do not melt or oxidise below 1600° C., and are thus highly satisfactory for very high-temperature measurement. Platinum alloys are rapidly attacked by furnace atmospheres, and must be protected by fused silica sheaths, which sometimes, where salt-bath temperatures are concerned, need themselves to be enclosed in iron sheaths or nickel-chromium heat-resistant alloy sheaths.

Platinum to platinum-iridium thermocouples give higher e.m.f. values than platinum to platinum-rhodium couples, but the latter are preferable for very high temperatures. Resistance changes substantially during heating in the furnace, and to minimise this effect, which influences temperature indications, the resistance of the entire circuit has to be made very large in comparison with that of the couple. This is done by using a high-resistance galvanometer incorporating an additional "ballast" resistance. Rare-metal couples are costly and the instrument itself delicate.

Base-metal thermocouples are cheaper, and have thicker and stronger wires. They have a lower electrical resistance, because the electrical resistance of a conductor is inversely proportional to its cross-sectional area; have a lower specific resistance; and develop an e.m.f. about three to four times as large as that of a platinum couple. In consequence, they may be made as strong as an ammeter. Not many base-metal couples are satisfactory over 1000° C. For such temperatures the chromel-alumel type are used, comprising one wire of an

alloy of 90 per cent. nickel, 10 per cent. chromium, and the other of nickel containing 2 per cent. aluminium. Couples of this type will measure temperatures up to 1300° C. The wires must be protected against reducing gases by enclosure in an iron or mild-steel sheath at temperatures below 900° C. or a nickel-chromium alloy-steel sheath for temperatures between 900–1000° C. If higher temperatures have to be measured with these couples, a fireclay sheath lined with silica must be employed.

The only satisfactory method of calibrating a pyrometer of thermo-electric type is to determine the e.m.f.s corresponding with a series of accurately known fixed points, the cold junction of the circuit being maintained at some constant temperature during the entire range of experiments. A series of e.m.f. values is obtained and a calibration curve plotted from the results, being later employed to convert millivolt readings into their corresponding temperatures. If the cold junction temperature is subject to temperature fluctuations, the e.m.f. or its corresponding net galvanometer reading is usually plotted against the *difference* between hot and cold junction temperature. The cold junction temperature at the time of a later determination is then added to that obtained from the curve.

In industrial installations, the indicator is usually directly calibrated in degrees of temperature and with the cold junction at about 15° C. When a temperature reading is required, the index of the indicator is then set at this cold junction temperature, the adjustment being made on an open circuit. E.m.f. temperature relations for commonly used thermocouples are:

Type	*Temperature Range*	*Formula (e.m.f. in millivolts)*
Chromel-alumel	0– 500° C.	$\log_{10}e = 1{\cdot}011 \ \log_{10}t - 1{\cdot}4113$
	500–1000° C.	$\log_{10}e = 0{\cdot}987 \ \log_{10}t - 1{\cdot}3466$
Iron-eureka	0– 500° C.	$\log_{10}e = 1{\cdot}031 \ \log_{10}t - 1{\cdot}3418$
	500–1000° C.	$\log_{10}e = 1{\cdot}0608 \log_{10}t - 1{\cdot}4216$
Platinum-platinum (10% rhodium)	0– 500° C.	$\log_{10}e = 1{\cdot}1470 \log_{10}t - 2{\cdot}4489$
	500–1000° C.	$\log_{10}e = 1{\cdot}2418 \log_{10}t - 2{\cdot}7042$
Platinum-platinum (10% iridium)	0– 800° C.	$\log_{10}e = 1{\cdot}0820 \log_{10}t - 1{\cdot}8729$

In industrial work, a standard thermocouple, if kept specially for this purpose, provides a trustworthy and expeditious means of calibrating a new or used thermocouple. The hot junctions of both thermocouples should be placed as near to each other as possible, gradually increasing the furnace temperature, so that there is no real difference in the temperatures of the two heated junctions. Corresponding readings are then taken every 50 degrees or so.

Radiation pyrometers are based on the law that the energy radiated by a hot body is proportional to its temperature multiplied by itself four times, so that the energy given out increases at a rapidly rising rate, i.e. $e = kt^4$ where k is a constant and t^4 is the temperature raised to the fourth power. The rate at which energy is radiated by a hot body varies with the material of which that body is made up and the state of its surface. Indicated temperatures may be converted into true temperatures by evaluating e in the logarithmic relation $\log_{10}e = 4 (\log_{10}t_0 - \log_{10}t_1)$, where t_0 is the true temperature ascertained by, for example, a thermocouple; t_1 is the indicated temperature; and e the emissive power of a substance. Emissive powers of various materials are as follows:

Aluminium, 0·20; graphite, 0·95; molten copper, 0·15; copper oxide, 0·60; molten brass, 0·28; molten iron, 0·28; iron oxide, 0·85; nickel oxide at 1000° C., 0·80; zinc oxide, 0·10.

If external conditions are reasonably constant, a radiation pyrometer may be most useful so long as its readings are considered as relative rather than absolute. Correction then becomes needless. The interior of a closed furnace functions as

a true black body. The radiation pyrometer is mainly valuable as a means of determining temperatures within an enclosed space, e.g. inside a furnace. Flame, dust, and smoke affect the intensity of the light emitted, and therefore may greatly modify readings. To prevent errors as a result, a porcelain or fireclay tube may be placed in the furnace and the pyrometer sighted on the closed end.

Optical pyrometers are mostly of disappearing-filament or polarising type. In both, the intensity of the light emitted by a hot object is matched against the light from a standard source. In the first, a hairpin-filament lamp is employed as the standard, the electric current through it being regulated until the image of the filament seen through the eyepiece just disappears into the field or area illumined by the body investigated. For temperatures over 800° C. screens are employed to lessen glare and make comparison easier. Between 800 and 1400° C. monochromatic screens are used, and for still higher temperatures an absorbing screen is placed between hot body and filament.

In the polarising optical pyrometer, a chosen ray of monochromatic light from the hot object is regulated to identical intensity with that emitted by a standard electric lamp lit up by the current from an accumulator. Taking the logarithmic relation

$$\log_{10}e_m = 1{\cdot}032 \times 10^{-4}\left(\frac{1}{t_2} - \frac{1}{t_1}\right),$$

it is easy to ascertain the emissivity e_m from the indicated temperature t_1 and the correctly known temperature t_2, measured by means, for example, of a thermocouple, and its calculated value may then be employed for the conversion of indicated temperatures. Emissivities of a number of important materials for monochromatic red light are: graphite, 0·95; molten copper, 0·15; copper oxide, 0·70; molten iron and steel, 0·4; iron oxide, 0·95; molten nickel, 0·37; nickel oxide, 0·9; molten silver, 0·10; molten gold, 0·22; molten platinum, 0·38.

SEGER CONE MELTING TEMPERATURES

Cone No.	° *C.*	*Cone No.*	° *C.*	*Cone No.*	° *C.*	*Cone No.*	° *C.*
010	950	2	1170	13	1390	24	1610
09	970	3	1190	14	1410	25	1630
08	990	4	1210	15	1430	26	1650
07	1010	5	1230	16	1450	27	1670
06	1030	6	1250	17	1470	28	1690
05	1050	7	1270	18	1490	29	1710
04	1070	8	1290	19	1510	30	1730
03	1090	9	1310	20	1530	31	1750
02	1110	10	1330	21	1550	32	1770
01	1130	11	1350	22	1570	33	1790
1	1150	12	1370	23	1590		

Like radiation pyrometers, optical pyrometers indicate true temperatures only when employed under true black-body conditions. If used in the open, their indications must be corrected by correction factors, unless the pyrometer is invariably used in the same circumstances and the readings are considered as relative only. Both types of instruments are portable and can be taken from point to point as required.

Fusion Pyrometers: The only other pyrometers that need be mentioned are the fusion pyrometers, including the Seger cones and the Brearley Sentinel pyrometer. The first comprise triangular pyramids of silicates that begin to soften or melt at previously ascertained temperatures. At the softening temperature, the cone apex leans over towards the base. Such cones have proved valuable in studying refractoriness or heat resistance in materials designed to make up crucibles and furnace linings. The Sentinel pyrometers are cylinders

of compressed salts coated with wax to avoid deliquescence. Either pure salts or eutectic mixtures may be employed. The cylinders are carried in small porcelain dishes and placed close to or upon the parts to be heat treated. They melt completely at the correct temperature, and are therefore very useful if for any reason the furnace pyrometer is out of action, and as a method of calibrating thermo-electric pyrometers.

THE PRINCIPLES OF HEAT TREATMENT

Change Points and Critical Temperatures.—If a steel is heated through an adequate temperature range, it will be found that at a specific temperature, which differs with each class of steel, important structural alterations begin to take place in it. Steel is made up of soft iron and a hard, brittle substance called iron carbide (Fe_3C). This specific temperature marking structural change is known as the change point, arrest point, critical point, or transformation point. It marks the point at which the carbon, as carbide, and perhaps other elements if the steel is of alloy type, starts to dissolve in the gamma iron, forming austenite. Eventually, if temperature is raised far enough, i.e. at the upper change point, all the steel will consist of austenite. The temperature range between the two temperatures concerned is termed the critical range.

At a correct temperature above the critical range, the steel is swiftly cooled by plunging it into a cold liquid. This is termed quenching, and it has the effect of freezing or fixing the structure produced by heating through the critical range. Sometimes the structure thus fixed is almost exactly that obtained by heating through the critical range, as when highly alloyed steels are dealt with. With other steels, however, the fully austenitic structure is not fixed, but the condition is still quite different from what would be obtained if the steel were allowed to cool down slowly in the open air. It is, in short, the martensitic structure that is then obtained, the iron being in the alpha or magnetic condition. Martensite is a very hard, brittle constituent of steel, and must be the major constituent of cutting steels.

Constructional steels must not have a martensitic structure, and although they may have to pass through the martensitic condition, as a result of a preliminary quenching or hardening, they have to be tempered to put them in the proper structural condition. This is done by heating them after hardening to a pre-established temperature *below* the critical range of the steel, usually below 600° C., and then cooling in air, water, or oil. This procedure is termed tempering.

The essential points to be borne in mind are that: (1) critical changes corresponding to a particular temperature range occur in steel when raised in temperature by heating (iron carbide is dissolved in gamma iron to form austenite); (2) a critical range corresponding to a particular range of temperature appears in steel that is cooled in the ordinary way below the lower change point, so that if cooling is not too quick or too slow, the steel's structure and properties will go back to what they were originally (normalised or annealed castings are an exception); (3) the change point on heating is a few degrees higher than the transformation range on cooling; (4) sharp cooling of steel in a cold liquid sets the structural condition to some extent; (5) this structure will be martensitic and hard, i.e. the iron carbide, instead of being dissolved in gamma iron to form austenite, will be held in the alpha iron (ferrite); (6) if steel is deliberately cooled at quicker or slower rates than the normal, various structures can be obtained as required in the cold steel; (7) an extensive range of properties can be had by skilful heat treatment because of the power of gamma iron and alpha iron to dissolve iron carbide, carbon, and other alloying elements.

The Hardening Temperature.—Hardening temperatures vary with the type of steel, being affected by chemical composition, the kind of structure and properties desired, and the size of grain, which, in general, is larger the higher the steel is heated above its critical range.

Mild and medium carbon steels (0·1–0·85 per cent. carbon) are, as a rule, seldom heated much above their upper transformation point, as this would only coarsen the structure. There are some exceptions to this, e.g. steels for easy machining, where coarse grain is an advantage from this point of view, and steels for wire-drawing; but these exceptions should be carefully considered.

Carbon steels with more than 0·85 per cent. carbon should be heated sufficiently far above the lower change point to form austenite by the dissolution of the iron carbide. On no account should they be heated higher than this, as otherwise their grain structure will be coarsened, and when quenched they will be brittle.

Alloy steels cannot be dismissed in a few words. In general, they have lower critical change points or ranges for cooling than the plain carbon steels, and they are so numerous and so complex that they must be considered individually in works of greater detail.

Heating Rate for Hardening.—Heating rate must usually be gradual, and is governed by the heat conductivity of the steel, the type of furnace atmosphere, and the sectional thickness of the steel being treated. Too sharp variations in section may produce harmful stresses, so that the thinner sections of a complicated piece should, wherever possible, be heated up more slowly than the thicker. Slow heating is more conducive to uniformity of temperature throughout the mass of the piece being treated, and so minimises distortion due to unequal stresses.

Heating Period.—Time is needed to dissolve the carbides. Structural changes are quicker at high temperatures than at low. When the correct temperature above the critical range is sustained for a period, the change is not only retained but enhanced. Maintenance of the maximum temperature gives, therefore, a more even structure, so long as this temperature is not too high. A good general rule is a total heating period of 1 hour minimum per inch of cross-section or thickness for hardening, and from 1½ to 2 times this period for tempering.

Temperature of heating is more important than time at temperature. Time at temperature becomes more important as mass increases, heat conductivity declines, and surface modification by furnace atmosphere becomes more likely. Heating period should, generally, be long enough to ensure even temperature throughout the mass of the steel and to produce the desired modifications of structure, but not so long as to set up scaling, decarburisation, or grain growth.

Cooling of Steel.—Relatively slow cooling produces steel with a somewhat coarse grain, low in strength and highly ductile. As cooling speed increases, the temperature of the lower change point is pushed lower down the scale, until finally it may be as low as 300–350° C. In some steels the cooling rate may be so high that no structural modification occurs, which is often what is required; but this is usually true only of alloy steels or those with above 1·2 per cent. of carbon. In the other steels, some structural change always takes place.

Quenching depresses the critical temperature range so that the change point is almost at room temperature, and the changes will not then be complete. The more massive the steel section, the harder it becomes to secure uniform structure throughout the mass. A heavy section cannot be cooled so quickly as a light, and the core will be different in properties from the case, leading possibly to unevenly distributed stresses causing distortion. Deeper hardening may be had by heating to slightly higher maximum temperatures in advance of quenching, producing a coarser austenitic structure, but this is not good practice.

HEAT-COLOUR TEMPERATURES

Colour	*Centigrade*	*Fahrenheit*
Just visible red	500°–600°	932°–1112°
Dull cherry-red	700°–750°	1300°–1385°
Cherry-red	750°–825°	1385°–1517°
Bright cherry-red	825°–875°	1517°–1600°
Brightest red	900°–950°	1652°–1750°
Orange	950°–1000°	1750°–1835°
Light orange	1000°–1050°	1835°–1925°
Lemon	1100°–1200°	2012°–2200°
White	1200°–1300°	2200°–2372°

Scale.—Scale left on parts to be cooled or quenched causes differential hardening of a part, and produces soft spots. It should, therefore, be removed before quenching starts, either by mechanical means or by hand. Preferably, however, it should be prevented altogether by use of an atmosphere-controlled furnace.

Tempering.—Tempering is designed to eliminate from steel, in the martensitic condition produced by quenching, the unevenly distributed strains and the brittleness inevitable after quenching, and to restore some of the toughness and ductility desirable in service. It comprises reheating the quenched material to a temperature below the lowest heating change point. With tool steels, tempering temperature is seldom more than 250° C. Alloy steels need higher tempering temperatures than carbon steels. Some steels are brittle when tempered at 300–350° C. or allowed to cool down gradually from these temperatures. They should, therefore, be tempered at temperatures below 300° C., or cooled quickly throughout this range if the steel has been tempered at over 350° C.

TEMPERATURES OF TEMPERING COLOURS

Tint of Oxide on Surface of Steel	*Centigrade*	*Fahrenheit*	*Suitable for*
Dark blue	316°	600°	Hand saws.
Blue	293°	560°	Fine saw blades, augers, boiler-makers' snaps, chisels, smiths' tools, and cold setts.
Bright blue	288°	550°	Watch springs, swords.
Purple	277°	530°	Table knives, large shears and wood-turning tools.
Brown, beginning to show purple	266°	510°	Axes, planes, and wood-working tools.
Brown	254°	490°	Scissors, shears, cold chisels, large drills, shear-blades, punches, and wood-cutting tools.
Golden-yellow	243°	470°	Penknives, hammers, taps, reamers, planing- and slotting-tools, small drills, screwing-, stamping-, and cutting-dies, and miners' drills.
Straw	230°	446°	Razor blades.
Pale yellow	221°	430°	Small edge-tools, small lathes-, planing-, and slotting-tools.

Quenching Equipment.—Steel is usually quenched in a cold liquid or an air blast. Cooling rate is often increased by moving the part in the quenching bath, or causing the quenching liquid to move about it. Large quantities of small parts are often passed through the quenching tank on a power-driven conveyer, or caused to descend into it by gravity. Large parts are sometimes suspended from cranes and caused to circle slowly about the bath. A different method is to employ a rotating screen barrel containing a worm, which catches up the quenched parts in its threads and keeps them turning over and over while moving forward through the liquid. Certain small pieces are allowed to fall through the quenching medium into a work basket, taken out when filled, or on to a conveyer placed on the bottom of the bath. When the work basket is employed, care should be taken to see that the parts drop far enough to give up all or most of their heat to the quenching medium before they come to rest.

Which method is used depends on kind, quantity, and dimensions of the parts. Gravity conveyers give a lower output rate but provide a more complete quench

than a mechanical conveyer, which is best kept for big quantities of mass-produced small pieces.

Circulating the Quenching Medium.—It is often cheaper and better to circulate the cooling liquid about the hot part than vice versa. If some circulation either of the part or of the medium is not attempted, steam pockets leading to soft spots are caused by trapping of vapour in recesses, under projections, etc. Methods of circulation of the quenching medium include liquid flow and pressure quenching. Liquid flow is the simple method of introducing the medium continuously by a pipe in the bottom and allowing it to pass out through another pipe near the tank top. Another method, sometimes combined with this, is to agitate the liquid continuously by revolving mechanically driven paddles or blades. In pressure quenching, the liquid is driven under pressure through jets either above or below the bath surface. This method may be employed to give particularly rapid cooling of local areas, if required, by suitable direction of the jets. Even quenching prevents or minimises distortion caused by unbalanced stresses. Shafts should be revolved while horizontal in the bath, and will warp less than if stationary.

Quenching Tank Volume.—Tank volume must be adequate to give full quenching, which means that there must be enough liquid to do the quenching work without ever becoming too hot to be effective. If oil is the quenching medium, this becomes increasingly important, because if the oil grows too hot, there is a distinct danger that it will ignite. Oil has a " flash-point," i.e. a temperature at which it will fire, and this should be known before the tank is designed. Another important point is that parts should not be continually quenched at one end only of the bath, unless proper circulating systems are in vogue.

The formula for calculating the minimum volume of quenching medium that must come in contact with the steel in a given period of time is :

$$\frac{W_1 \times SH_1(T_1 - T_2)}{SH_2 \times W_2 \times TR} = \text{cu. ft. of quenching.}$$

Here, W_1 is the weight of the material being quenched ; SH_1 is the mean specific heat of the material quenched ; T_1 is the temperature of the heat-treated material ; T_2 the temperature of the material on withdrawal from the tank ; SH_2 is the specific heat of the quenching medium ; W_2 is the weight per cubic foot of the medium ; and TR is the permissible rise in temperature of the quenching medium. This formula, however, is not valid for calculating the size of a tank without forced circulation unless all the medium is near enough to the steel to absorb heat, or the period between quenchings long enough to allow of even heat distribution throughout the bath. If the quenched pieces are not immersed below a given depth, the medium below this point will be unheated and must not be included in the formula, but calculated independently. The formula must not be employed to ascertain the volume to be provided by pumps.

For only a few parts, a plain quenching tank can be used without special circulating devices, so long as the volume is adequate. For small heat-treating plants, a large water jacket placed round the tank will serve to keep it cool. The water in this jacket may be either stationary or circulated. A better method is to cool the bath by coiled pipes carrying water or a salt solution, either inside the tank or wrapped about it. In large heat-treating plants, a series of baths may be fed by a large central storage tank by mechanical circulation. This enables a tank to be taken out of the line for cleaning or repair without complete interruption of the work. The main storage tank may itself be cooled by pipes.

Sometimes the quenching medium is atomised to give maximum cooling before being sprayed into the tank, thus offering a large surface area to the cooling action of the air, but if this method is used for oil, a fire risk exists and must be guarded against. A further method is to circulate the medium through pipes, not coiled but wrapped about the tank, the pipes being either exposed to the air or enclosed in a cold-water tank. Sometimes it is the cooling medium that goes through the pipes, and the quenching medium is passed over the pipes in a shallow stream. This is an effective but expensive method. Mechanical refrigeration of the quenching medium is possible, and plant to achieve it may be had, but is costly and high in maintenance charges.

Oil Flash-point.—To prevent firing of oil, a spare pump should be kept if a circulating system is employed. In the event of fire, the pump should go on running, because the circulation lowers the oil temperature. If possible, it should be run at higher speed. Do not run the pump if it serves a number of tanks, only one of which has fired. Oil fires are not swift, and may sometimes be extinguished by mere stirring of the bath. A tank lid should be made and placed in position. This keeps out air and will quickly smother the fire. A foam extinguisher will serve if no lid is available, its action being kept to the surface. Water must not be employed.

Mechanised Quenching.—Modern quenching and auxiliary equipment is highly mechanised. In a typical plant, the charge is elevated and lowered on to a quenching rack by a wire rope, on which it hangs from an overhead drum, gear-driven. Rack movement is push-button controlled in conjunction with limit switches. Oil coolers prevent overheating. The tanks hold 15 tons and are hooded, fumes being withdrawn by fan exhausts inside the ducts from the hoods. Rapid charging and conveying equipment takes the load from the furnace to the quenching tank on an all-electric charging machine, moving at 250 ft. a minute.

Hardening High-speed Steel.—Hardening is a process designed to produce a steel as hard as possible consistent with serviceability. To achieve this, the steel has to be brought to a temperature above the critical range, then quenched. The hardening temperature should never be more than 30–50° C. above the upper critical point. Hardness is greatly affected by dimensions and mass of the piece. The factors affecting the hardness of a high-speed steel are: (1) mass; (2) surface area per unit volume of the piece; (3) extent to which heat soaks thoroughly into and is distributed evenly over the entire mass; (4) cooling speed; (5) hardening temperature; (6) alloy contents; (7) carbon percentage; (8) grain size; (9) quenching medium; (10) temperature of quenching bath; (11) speed of circulation of quenching medium.

Tempering Colours.—In tempering steel, a balance must be struck between hardness and stress relief. Tempering produces oxide colours on the surface of the steel being treated, and these colours have a close relation to the different tempering temperatures. Table on p. 172 shows the correspondence. After having been hardened, the steel is rubbed with emery, and as its temperature rises during the heating for tempering, the normal bright surface takes on the typical iron-oxide hues. Complete reliance on these tints is not advisable. Bad lighting conditions may cause misjudgment of the tints. Moreover, the colours are themselves partly affected by the length of the period during which the tempering temperature is maintained. Temper colours show only *surface* temperatures, and as the surface increases in temperature the colours change. When the ultimate correct tempering temperature is attained, if heating goes on the colour will alter without any corresponding change in temperature.

Liquid Tempering Baths.—In modern tempering, liquid baths are used for the heating operation, so as to do away altogether with the surface oxide tints. The reason is that as tempering temperature is judged solely by temper colour, the moment the right tint is attained the steel must be cooled, because the operator cannot know the precise moment when the colour will change again. Quenching is not advisable, because it reintroduces strains and unevenness of structure, while there may also be variation in hardness in one and the same piece.

Tempering Methods.—(1) The tools are placed on a cast-iron plate with a smooth machined surface, heated from below; (2) the tools are placed on a tray or dish filled with sand, which is afterwards heated on either the cast-iron hot plate or in a furnace; (3) the parts are heated in an oil bath; (4) parts are heated in a salt bath; (5) in the lead bath; (6) in the electric furnace.

Method (1): Position of tools must be periodically altered, and the moment the right temper tint is seen they should be quenched.

Method (2) has the advantage that a thermocouple may be employed to give a precise indication of tempering temperature, the temper tints then serving merely as an additional indication. The sand used has to be clean and free from moisture. Tempering by this method is more even than by method (1), but only small parts should be tempered in this way.

Method (3) *:* The bath must be heated to the precise temperature and kept steady at this heat for a period. Hence, precise measurement of temperature is vital. The oil bath should not be used for temperatures over 260° C., but at lower temperatures than this is very good. Mineral oil is usually employed. A wire basket containing the parts to be tempered is suspended in the bath before it has attained 100–150° C. This ensures gradual heating and gentle stress relief, thus preventing fracture. Moreover, suspension in the work basket keeps the parts away from the hot container and prevents local overheating. Tempering temperature is generally maintained for a quarter of an hour. Larger parts need longer, but smaller parts heated with them will not be harmed by this longer maintenance period. After tempering, small parts are taken out and cooled in air. Very large pieces may cool in the bath, so avoiding warpage.

Method (4) *:* The salt bath is mainly employed for tempering temperatures higher than 260° C., and is composed of 40 per cent. potassium nitrate and 60 per cent. sodium nitrate. The salt bath may be used without risk for tempering up to temperatures of 540° C. A work basket is employed here also.

Method (5) *:* The lead bath follows the same general principles as the salt and oil baths, but is employed for tempering temperatures over 330° C. The lead must be prevented from sticking to the surface of the work by the method outlined in an earlier section on lead baths.

Method (6) *:* Electric tempering furnaces are designed primarily for springs, bolts, pressings, etc. They give a nice, even heating even if the parts are closely packed. Usually they are of forced air-circulation type, and may be employed at temperatures so low that oxidation and scaling hardly occur.

Normalising.—Normalising is a method of cooling steel designed to produce the "normal" tensile strength, yield point, elongation, and reduction of area; to give a superior surface finish after machining; and to give back to bars rolled at a low temperature the ductility lost, while simultaneously making them more homogeneous. It differs from annealing in that the steel is allowed to cool down in the air instead of in the furnace. There is no such thing as a characteristic "normalised" structure, because the structure itself varies with the size of the part.

The normalising temperature when reached is usually maintained to ensure uniformity throughout the mass for at least a quarter of an hour; but larger pieces may need longer. The normalising temperature must never rise to more than 50° C. above the upper critical point of the steel.

Normalising produces a rather less ductile steel than annealing, but gives higher mechanical properties and finer grain, as well as greater resistance to impact. These improvements are more apparent with low- than with high-carbon steels. Normalising in advance of case-carburising is usually done from a high temperature to produce the requisite coarse grain. Temperatures over 980° C. may be required in some instances. Normalising also prevents distortion of the steel after machining and before case-hardening.

Annealing.—Annealing is a process in which steel is reheated and slowly cooled in the furnace. It is intended to soften steel for mechanical working or machining, and to relieve internal stresses produced by earlier operations involving swift cooling or severe deformation. Annealing also improves grain structure, and is often indispensable before hardening, as with high-speed steel, to prevent cracking. Annealing temperatures are generally above the lower critical point, and with carbon steels above the critical range. In some circumstances, however, a sub-critical annealing may be needed.

Sub-critical Annealing.—Here, the temperature to which the steel is reheated is lower than the lower critical point. Air-hardening nickel-chromium molybdenum steels are softened in this way by the spheroidisation of their carbide particles. High-carbon tool steels may be similarly treated.

Annealing Temperatures.—The reheating temperature is dependent on the carbon and alloy percentages. Steels of unalloyed type with less than 0·9 per cent. carbon are reheated to slightly over the upper change point. Plain carbon steels with higher carbon than 0·9 per cent. are heated to a point within the critical range. The majority of high-carbon tool steels are reheated to between 760–780° C.

The annealing temperature must be maintained for the correct period, which is important and depends on the type of steel, etc. After completion of the annealing process, the annealed steel is as soft as it can be in the cold state.

Preventing Oxidation.—To prevent oxidation and scale during annealing, the steel may be packed in a mixture of burnt lime reduced to a very fine powder, and containing a small amount of powdered charcoal. Lime is rammed into a carburising box, the material placed on this layer, and a further lime layer tightly rammed above it and charcoal scattered over this. The box is then sealed with clay, and the result is a scale-free metal. If necessary, several layers of parts may be dealt with in this way. The method is not much used to-day owing to the development of bright-annealing furnaces. Rod or wire for cold drawing may be annealed in cast-iron pots packed with cast-iron chips.

Mode of Operation for Annealing.—The charge must be raised above the furnace hearth on supports made of heat-resisting alloy steel or refractory bricks. Each part must be separate from the next. The furnace must not be overcharged or heat will be unevenly distributed. Heating must be slow, gradual, and uniform. Too swift heating may cause cracking and steel inadequately soft, as well as warping and possible spoiling. High-carbon steels should be reheated more slowly than mild steels. Intricate parts should be preheated carefully before being placed in the hot furnace. High-speed steels need extremely slow and careful preheating. Annealing temperature is governed by chemical composition of the steel and carbon percentage.

Heating for Annealing.—Steel should not be heated above the proper annealing temperature in an endeavour to speed up the process, as this causes brittleness and possibly complete ruin of the steel. Heating period depends on the maximum cross-sectional dimension of the part, since the flow of heat depends on temperature gradients. Structural condition before annealing also affects heating period. A good general rule is ½ to 1 hour per inch of section, but usually heating is faster when higher output is desired.

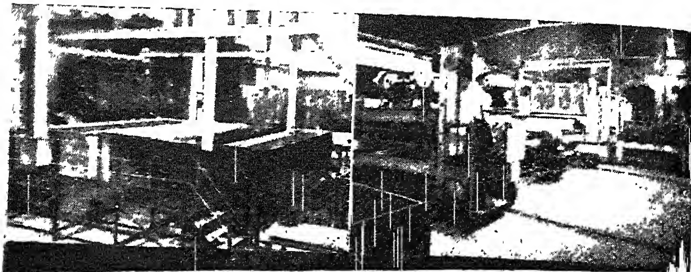
A useful tip is to pass electric current through the piece, whose resistance generates heat, which is maintained until the piece is completely soaked. This is a speedy process, enabling a higher temperature to be adopted with no enlargement of grain structure, and with even distribution of heat.

Cooling period is longer for larger masses, and the cooling rate is controlled by the size, form, and method of construction of the furnace. The slower the cooling through the critical range, the better the result.

Annealing Outside the Furnace.—Where pieces cannot be cooled down in the furnace, or for some reason the furnace is urgently required for other work, cooling may be carried out in ashes, lime, or sand, materials of low heat conductivity. Larger pieces may be placed in a cooling pit lined with brick or metal plates and with a metal cover, and possibly buried in ashes. In both instances the cooling rate will be rather slower than in the furnace, but yield point and tensile strength will not be so high (except with austenitic stainless and manganese steels).

Annealing Cast or Overheated Steels.—These require longer soaking periods because the coarse grain structure takes longer to refine. Several days may, in some instances, be necessary for complete heat-saturation. Special heating procedures may be needed, and a double annealing treatment be required. Where these methods prove ineffective, as with badly overheated steel, a temperature 100–150° C. above the upper critical point may serve. The steel must be completely soaked at this temperature, and afterwards cooled to a point below the lower critical point. This cooling should be in air if the furnace cooling will not produce full elimination of bad structure. If, on the other hand, it is reasonable to suppose that the high temperature has sufficed to restore the structure, cooling may be in the furnace. A complete normal annealing treatment then follows, and produces the refinement of grain structure rendered necessary after the high temperature.

Case-hardening.—Steel parts that have to meet shock, wear, abrasion, and fatigue need an extremely hard surface together with a tough internal structure or core. This condition is obtained by case-hardening, which comprises two processes: (*a*) heating to a particular temperature in a liquid, solid, or gas, rich in



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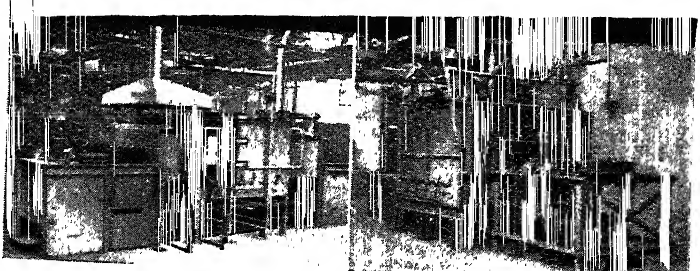

carbon; (b) a separate heat treatment—(a) adds carbon to the steel at the surface and to a certain extent below it; (b) provides the requisite hardness to the surface and toughens the core. There are three case-hardening processes: (1) pack hardening; (2) gas carburising; (3) liquid carburising.

Pack Hardening.—The parts are enclosed in a box or tube together with a powder rich in carbon. The box is sealed with clay to shut out air. This is the simplest and most usual method, but takes a considerable time, and labour cost is heavy in packing and unpacking the containers. Parts must be well cleaned before insertion in the box, dirt, scale, grease, etc., being removed to prevent soft spots. The parts are then heated to 900–920° C. according to composition of the steel. The carbon content of the case is normally approximately 0 85 per cent., the core remaining unaltered.

Cooling down is in the box. The first heat treatment is to heat the steel to a temperature just above its upper critical point (915–925° C. for fine-grained steels, 940–955° C. for those cases in which a correctly designed furnace and accurate temperature control are available). Quenching in water follows. This refines the core. More usually, lower temperatures (885–900° C.) are used to obviate distortion. Very small or thin parts that must not have a heavy carburised case should be heated to 845° C. A good normal case after pack hardening is 0·025 in.

A second heat treatment is given to improve the ductility and impact resistance of the core and the case. The parts are reheated to 760–780° C. Where for reasons of cost a single treatment only is required, this can be a direct quench from the case-hardening temperature or a reheating to approximately 900° C., succeeded by quenching, or a reheating to and quenching from approximately 830° C. The first of these practices is not recommended. The second practice is better, but does not produce the most shock-resistant parts.

Gas Carburising.—The parts are placed in a furnace chamber into which a carbon-containing gas is introduced, usually a mixture of suitable gases, i.e. a hydrocarbon with a diluent. Gas carburising is high in first cost of equipment, and to be economical needs high production from a large unit.

Liquid Carburising.—This is designed to produce a somewhat thin case at medium temperatures, and should be confined to cases not more than 0·03 in. in thickness. The process is highly suitable for continuous operation and automatic quenching, is cheap, and is carried out in an activated bath of calcium cyanamid with polymerised hydrocyanic acid, or sodium or potassium cyanide with a salt or salts. The optimum working temperature is from 815 to 900° C., but the upper end of this range is principally employed, except for the thinnest cases. Heating time depends on depth of case, 3–3½ hours being necessary for the maximum case depth that is economical to produce by this method. A case 0·01 in. thick needs about 45 minutes. Heavy sections need longer.

Carburising Compounds.—Charcoal, charred leather, crushed bone or horn, potassium ferrocyanide, and barium carbonate are possible. The best mixture is probably 60 per cent. wood charcoal plus 40 per cent. barium carbonate. Most commercial compounds employ approximately 20 per cent. of an alkaline or metallic carbonate with a binder, e.g. oil, tar, or molasses; 20 per cent. powdered coke is added to conduct heat and produce more uniform temperatures in the box. The mixture should never be used twice.

Carburising Furnaces.—The carburising temperature must be kept within plus or minus 5° C. with uniform heating throughout within 10° C. Oil-fired furnaces are inadvisable because temperature varies too much. A continuous pusher furnace gives a high production, and is suitable when only moderate depth of case and as low a heating time as possible are needed. For gas carburising, batch furnaces may be gas fired or electrically heated, and comprise a horizontal or vertical retort. The horizontal retort can be fixed or rotary. If rotary, it should be employed for only the most robust parts. It is low in first cost and prevents the depositing of carbonaceous particles on the parts, causing soft spots. The vertical retort is coming into wider use because it produces a highly uniform case. A mechanical gas stirrer may be combined with it, and serves to improve case uniformity. The continuous pusher furnace costs less to operate than the same type of furnace for pack hardening so long as it works to maximum capacity,

but if not, it ceases to be economical. For liquid carburising a metal pot is used, and may be a steel casting, a welded sheet-steel container, or a heat-resisting steel casting. The pot is heated by either gas, oil, or electricity.

Case-hardening Steels.—Plain carbon case-hardening steels seldom contain more than 0·2 per cent. carbon and 0·5 per cent. manganese. The effect of the process is to produce a steel with a case having a carbon percentage of 0·85 per cent. shading gradually into a core with 0·15 per cent. carbon. Stronger steels are made by adding alloys, and of these the most popular are the nickel case-hardening steels with 3–3½ per cent. nickel (sometimes 5 per cent.), which may be quenched either in oil or in water, according to the core strength desired. Nickel-chromium steels may be employed to give specially strong cores and a more wear-resistant case.

With almost all these steels, double quenching is better than single quenching. Tempering between 100 and 200° C. is beneficial, and essential after the final quenching of the nickel-chromium steels. It relieves strains and minimises distortion or cracking.

Carburising Containers.—These are usually made of heat-resisting steel or a nickel-chromium alloy known as "Nichrome." They are mostly cast, but some are made of welded sheet steel. Castings are more economical and may be cast with walls of less thickness, thereby giving a briefer heating period and therefore lower cost, with less risk of failure. Mild rolled steel or unalloyed steel castings are now seldom used. Tubes or cylindrical containers are better than square or oblong boxes because more even heating becomes possible. Separate tubes inside boxes have been used.

Causes of Case-hardening Failure.—(1) Failure to clean off dirt and scale before treatment, causing soft spots; (2) inadequate carburising period and careless packing in the compound, causing uneven case thickness; (3) excessive grinding, causing soft spots or completely removing case; (4) parts touching furnace walls, causing soft spots; (5) wrong furnace atmosphere, causing severe decarburisation; (6) too low a second reheating temperature, causing too soft a case; (7) defective steel; (8) faulty quenching—temperature too low, medium dirty or too hot, or steam pockets formed through inadequate circulation; bad quenching causes brittleness of core or soft spots; (9) bad carburising compound or too high a carburising temperature, causing flaking.

Cyaniding.—A case-hardening process employing sodium cyanide (sometimes, but rarely, potassium cyanide). The cyanide may be sprinkled on the hot steel at a temperature that causes it to liquefy, but usually a molten salt bath is used, the cyanide being mixed with a salt (sodium chloride, barium chloride, etc.) to reduce its melting temperature. The outer layers of the steel absorb carbon and nitrogen, and after being quenched the steel has a good hardened case. A suitable salt solution is 45 per cent. sodium cyanide, but for low cost and stability with high production a 30 per cent. solution can be employed. Cyaniding is not suitable for producing cases of considerable depth. Time taken is generally 30–60 mins. One hour at 645° C. will yield a case depth of 0·62 in. in a mild steel. The process is mostly employed where maximum production at minimum cost is desired, or where the case is more nearly what the user desires than that given by case-hardening. The normal cyaniding temperature range is 775–845° C. Quenching should take place immediately on withdrawal, before the steel has cooled. Oil or water quenching may be adopted according to purpose. Mineral oil is advised. The latest cyanide furnace is of the electric type operated by A.C. current, electrodes being introduced into the bath. It is claimed to give lower operating cost and a more uniform temperature, greater production, and working conditions more favourable to the operator.

Nitriding.—A case-hardening process in which the hardened case is given by heating up the parts in an atmosphere of a nitrogenous gas, usually ammonia. The great economic advantage of the process is that no heat treatment is afterwards required, while the steels employed are different in composition from those employed for case-hardening. The relatively low temperature of the process minimises distortion. Nitriding steels are normally ready for treatment as supplied, but forgings must be stress-relieved after forging within the temperature range 1065–1200° C.

Soft skin must be eliminated by grinding or machining, and stresses thereby occasioned relieved by heating to 650–700° C. for 1–4 hours according to dimensions, after which finish machining or grinding is carried out. Forgings are in the annealed condition, and after rough machining are heated to 925° C., quenched, and tempered at 620–730° C., then finish machined or finish ground.

The parts for nitriding are heated within the range 500–650° C.—usually 510–540° C. Nitriding furnaces may be oil, gas, or electric. A semi-continuous furnace of electrical type is favoured by many operators. This has two containers on stationary hearths. The heating chamber is mounted on wheels so that it may be placed as required over either receptacle, thus dispensing with the need to handle hot receptacles. Disconnection of ammonia pipes is also avoided. The best nitriding pots are those made of 80/12 or 20/25 nickel-chromium heat-resisting alloy. They must be thoroughly sealed.

NITRIDING STEELS

Typical Composition									*Diamond Brinell Hardness of Case*	*Max. Stress (tons per sq. in.)*
C	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*Al*	*Va*	*W*		
0·2	0·25	0·5	0·25	3·0	0·4	1·1			800–900	50·5
0·4	0·25	0·55	0·25	1·6	0·25	1·3	max.	max.	1050–1100	56·5
0·3		0·6	0·55	1·10	1·05		0·25	1·0	600–650	57·0
0·25		0·55	0·25	3·20	0·5		0·25	1·0	800–900	61·0
0·4	0·2	0·5	0·25	1·95	0·3		0·15	1·0	750–800	66·5
0·35	0·25	0·5	0·3	3·25	0·5.		0·25	1·0	800–900	63·0

Heat Treatment of Gears.—Higher-carbon steels should be employed for larger gears. Cooling from quenching should be slower for higher-carbon steels. Water or brine is the medium to use for carbon-steel gears up to 0·4 per cent. carbon, and water or oil for higher-carbon steels. To forge, heat to 1150–1280° C. Do not forge below 800° C. To normalise, heat to 850–870° C. and cool in the air. To anneal, soak well at 850–870° C. and cool in the furnace. To harden, heat to 830–850° C. Lower rather than higher quenching temperatures should be adopted to minimise distortion. Quenching oils should be heated to between 30–50° C. Do not water quench gears with sharp section changes. Quenching water may be warmed, but not to more than 50° C. Caustic-soda solution (4 per cent. caustic soda by weight) is a good medium for the larger gears. It should be warmed. The time water quench is good for gears that cannot be completely water quenched. The gear is kept in the quenching bath for a short period only, cooled in air till the internal heat has spread to the exterior, then cooled as usual. Temper within the range 200–450° C.

Heat Treatment of Alloy-steel Gears.—Forge between 1150 and 1250° C. Do not forge below 900° C. To soften for machining, reheat to 660–690° C. Harden at 780–870° C. Temper at 200–260° C. according to tensile strength desired.

TYPICAL GEAR-STEEL COMPOSITIONS

CARBON STEELS

0·4 per cent. carbon, 0·75 per cent. manganese.
0·45 ,, ,, 0·75 ,, ,,
0·45 ,, ,, 0·5 ,, ,,
0·5 ,, ,, 0·75 ,, ,,

ALLOY STEELS

C	*Mn*	*Cr*	*Va*	*Ni*	*Mo*	*W*	*Quenching Temp. ° C.*	*Temper at ° C.*
0·3	0·5	—	—	3·0	—	—	810–830	200–250
0·45	0·75	—	—	3·5	—	—	800–820	200–250
0·4	0·75	0·6	—	1·25	—	—	800–825	200–250
0·5	0·75	0·6	—	1·25	—	—	780–800	200–250
0·35	0·45	1·05	—	1·75	—	—	810–830	200–250
0·3	0·6	0·75	—	3·35	—	—	800–820	200–250
0·3	0·5	1·25	—	4·25	—	—	820–830	250 (max.)
0·45	0·75	0·95	—	—	0·2	—	830–850	230–260
0·4	0·65	—	—	1·8	0·25	—	810–830	200–230
0·4	0·75	0·95	—	—	—	—	825–850	200–230
0·5	0·7	1·0	0·2	—	—	—	850–870	200–230
0·4	0·75	1·0	0·15	—	—	—	850–870	200–230
0·35	0·4	1·25	—	1·9	—	0·45	840–850	200 (max.)
0·25	0·4	0·5	—	2·0	0·4	—	820–840	200 for 100 tons
0·35	0·8	1·0	—	3·0	0·7	—		660 for 65 tons

Quenching Media.—There are thirty-two known quenching media. The cheapest, simplest, and most used is water, after which comes brine. These have a high cooling rate and are most effective for the carbon steels. They cool at 982° C. per second. Oil cools less swiftly than water, and cools more slowly as the mass of the piece increases. Oil-cooled steels are less liable to distort because of the slower cooling. Oil is more suitable for alloy steels than for carbon steels. If even oil may cause warping, air must be used as a quenching medium. This cools still more slowly, and to make up for the loss of hardness resulting from this gentler cooling action, more alloys must be introduced into the steel's composition. Thus, air hardening is mostly used for expensive steels, such as high-speed steel.

The five main quenching media are: (1) brine; (2) water; (3) solutions of special compounds; (4) oils; (5) air. A typical special solution is sodium hydroxide and sulphuric acid in water. Action of these media depends on medium, quenching temperature at time of quenching, and cooling volume velocity, i.e. the speed at which all the medium is circulated. Volume of quenching bath, steel temperature, and method of immersion also play a part.

Quenching power is decided by: (*a*) heat conductivity; (*b*) viscosity; (*c*) specific heat; (*d*) vaporising temperature. Calcium chloride or sodium hydroxide is introduced to minimise vaporisation. Soap increases vaporisation, and must therefore be kept carefully out of the bath. Salt percentage should not be above 10. Quenching oils should not have a boiling-point below 380–400° C. They should have minimum carbon content, low water content, and low fatty-oil content. They must not decompose or thicken with repeated use, and should be fluid when fresh.

Heat Treatment of Plain Carbon Steels.—*Steels up to 0·25 per cent. carbon:* A modified hardening treatment is given by heating to 840–870° C. according to carbon percentage, followed by quenching in water or oil according to purpose. Temper after quenching all but the steels below 0·2 per cent. carbon and 0·6 per cent. manganese within the range 450–550° C. Process annealing or normalising is carried out at an average temperature of 880° C. The main point is to carry out this operation just above the critical range of the particular steel. Cool in air, except for bright annealing in a special furnace.

Steels up to 0·35 per cent. Carbon: Normalise, quench, and temper. Normalise within the range 800–830° C., and cool slowly, in the furnace, in lime, or in ashes. Sub-critical annealing is necessary after severe cold work. Heat to 680–700° C. and cool as above. Quench at 850–880° C. according to carbon percentage.

Steels up to 0·45 per cent. Carbon: Quench smaller parts between 830 and 870° C.,

larger parts 850 and 900° C. Quench in water, or oil if desired for large parts. Temper between 500 and 650° C. Plates and sheets can be heat treated for cold pressing by sub-critical annealing or spheroidising at 680° C., or by annealing at 850° C.

Steels up to 0·6 per cent. Carbon: Anneal after forging between 810 and 850° C. Harden between 800 and 850° C. Harden in water, brine, caustic-soda solution, or oil, according to purpose and danger of warping. Stress relieve at 150–250° C. according to purpose.

Heat Treatment of Carbon-steel Castings.—Anneal at a temperature 50 per cent. above the Ac_3 point (usually 850° C.) for several hours (1 hour per inch of cross section), but not more than 12 hours. Normalising at the same temperature will give a closer grain structure, improve tensile strength and yield point, impact resistance, and reduction of area. Do not normalise complex parts with sharp sectional changes. Quenching and tempering are not advised by most metallurgists owing to the risk of cracking. To carry it out, heat to 855–885° C. and quench in water or oil. Soaking at temperature should be for approximately 15 minutes per inch of diameter or thickness for quenching, and at least 2 hours per inch of section for tempering.

COMPOSITIONS OF CARBON-STEEL CASTINGS

C	*Si*	*S*	*P*	*Mn*	*Tensile Strength tons per sq. in.*	*Elongation per cent. in 2 in.*	*Izod*
0·25–0·3	0·2	0·05	0·05	0·4–0·7	34·0	28	—
0·3 –0·35	0·2	0·05	0·05	0·4–0·7	35·4	26	—
0·25–0·35	0·2	0·05	0·05	0·4–0·7	35–45	25 (minimum)	30
0·32	0·2	0·05	0·05	0·4–0·7	36·0	34	90, 91, 92
Elongation and Izod figures are after suitable heat treatment							
0·35–0·45	—	—	—	0·4–0·8	36·8	25 (annealed)	—
0·35–0·45	—	—	—	0·4–0·8	30·2	30 (spheroidised)	—

Castings should not be taken from the annealing furnace at a temperature above 300° C. Straightening of warped castings may be done by heating gradually and uniformly to 450–600° C. and afterwards cooling in air.

Heat Treatment of Alloy-steel Castings.—Normalising is usually carried out at rather higher temperatures than with carbon-steel castings, the range being 845–925° C. according to carbon content. Cooling is in the air. Heating time is approximately 1 hour per inch of thickness or cross section. Certain molybdenum steels may be normalised at 950° C. Double normalising is sometimes carried out to give a fine grain structure, usually at 10–20° C. above the upper critical point, heat being held from 30 to 60 minutes. Quenching should be carried out at 10–25° C. above the upper critical point. Tempering should follow at 675° maximum, but may go as low as 175–230° C. for 2 hours for small castings and 4–10 hours for large castings. Straightening warped castings may be done by heating to 260–480° C. and cooling in air after the operation. Castings should be stress relieved after welding or oxy-acetylene cutting.

Heat Treatment of Carbon Tool Steels.—There are six main temper groups: (1) 0·6–0·75 per cent. carbon; (2) 0·75–0·9 per cent. carbon; (3) 0·9–1·05 per cent. carbon; (4) 1·05–1·2 per cent. carbon; (5) 1·2–1·35 per cent. carbon; (6) over 1·35 per cent. carbon. None of these steels should be forged at temperatures below 750° C. For groups (4), (5), and (6) heat for forging to 850–900° C., and for groups (1), (2), and (3) to 900–950° C. Normalise groups (1) and (2) at 840–860° C., groups (3) and (4) at 800–820° C., and groups (5) and (6) at 780–800° C. Cool freely in air. Heat large sections for 45–60 minutes per inch of diameter or thickness, and maintain at temperature for one-third to one-half of heating period.

Steel No.	*Typical Composition Per Cent.*	*Anneal at ° C.*	*Normalise at ° C.*	*Temper at ° C.*
1	Chrome-vanadium steel: 0·3 carbon, 0·75 manganese, 0·35 silicon, 0·2 vanadium	—	900	650
2	Chromium steel: 0·35 carbon, 0·75 manganese, 0·4 silicon, 0·95 chromium	—	900–840	370–650
3	Nickel steel: 0·2 carbon (max.), 0·75 manganese, 0·4 silicon, 2·0 (min.) nickel	—	950–840	675
4	Nickel steel: 0·3 carbon, 0·75 manganese, 0·4 silicon, 3·5 nickel	—	925	675
5	Nickel steel: 0·25 carbon, 0·9 manganese, 0·35 silicon, 2·1 nickel	—	900	650
6	Molybdenum steel: 0·25 carbon, 0·9 manganese, 0·5 silicon, 0·4 molybdenum	— (1)	980–900	690
		(2)	925	—
7	Carbon-manganese steel: 0·3 carbon, 1·4 manganese, 0·35 silicon	— (1)	925	—
		(2)	900	675
8	Chrome-vanadium steel: 0·3 carbon, 0·75 manganese, 0·4 silicon, 0·95 chromium, 0·15 vanadium	—	900	650
9	Nickel-chromium steel: 0·35 carbon, 0·75 manganese, 0·4 silicon, 0·8 chromium, 1·4 nickel	925	900	675
10	Chromium-molybdenum steel: 0·3 carbon, 0·6 manganese, 0·8 chromium, 0·3 molybdenum	870	—	—
11	Chromium-molybdenum steel: 0·25 carbon, 0·5 manganese, 5·25 chromium, 0·5 molybdenum	—	950–980	650
12	Manganese-chromium steel: 0·4 carbon, 1·4 manganese, 0·5 silicon, 0·6 chromium	900	840	370
13	Manganese-nickel steel; 0·3 carbon, 1·25 manganese, 1·4 nickel	—	870	650
14	Manganese-molybdenum steel: 0·3 carbon, 1·2 manganese, 0·35 silicon, 0·35 molybdenum	—	925	590–650
15	Nickel-molybdenum steel: 0·3 carbon, 0·7 manganese, 1·3 nickel, 0·3 molybdenum	1010	925	730
16	Copper-manganese-silicon steel: 0·15 carbon, 1·15 manganese, 1·0 silicon, 1·8 copper	900	—	—
17	Copper-nickel-molybdenum steel: 0·2 carbon, 0·75 manganese, 0·6 nickel, 0·2 molybdenum, 1·0 copper	—	925–900	650
18	Manganese-nickel-vanadium steel: 0·3 carbon, 0·9 manganese, 1·5 nickel, 0·14 vanadium	—	950–840	590–650
19	Nickel-chromium-molybdenum steel: 0·3 carbon, 0·7 manganese, 0·8 chromium, 1·75 nickel, 0·3 molybdenum	—	980–815	540–67[illegible]
20	Manganese-vanadium steel: 0·3 carbon, 1·5 manganese, 0·4 silicon, 0·1 vanadium	—	900–815	400–56[illegible]
21	Nickel-manganese steel: 0·3 carbon, 1·45 manganese, 0·4 silicon, 1·4 nickel	—	900–840	565–650
22	Manganese-titanium steel: 0·3 carbon, 1·5 manganese, 0·4 silicon, 0·05 titanium	—	955–840	400–565
23	Nickel-vanadium steel: 0·29 carbon, 0·1 manganese, 0·4 silicon, 1·5 nickel, 0·1 vanadium	—	925–815	400–650
24	Chromium-manganese-silicon steel: 0·35 carbon, 1·4 manganese, 0·65 silicon, 0·45 chromium	—	900–840	370–675

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18% SaBeN EXTRA TUNGSTEN
22% SaBeN KERAU TUNGSTEN
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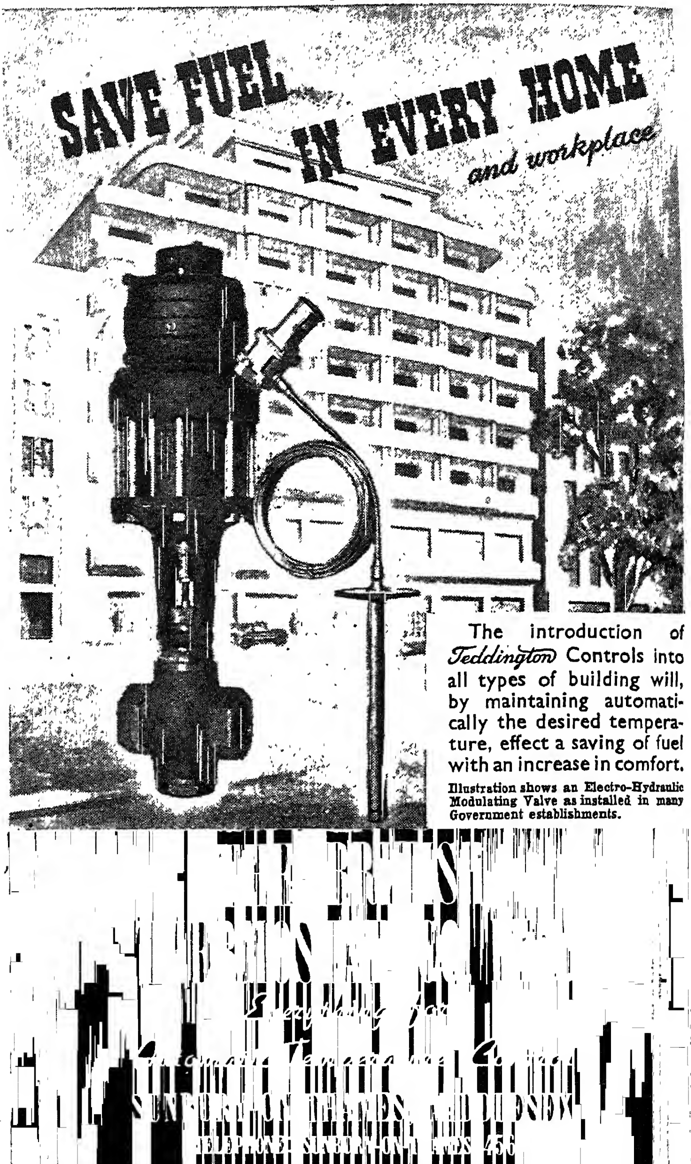
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To harden, heat groups (1) and (2) to 800–820° C., groups (5) and (6) to 760–780° C., group (3) to 780–800° C., and group (4) to 760–780° C. Quench in water or brine. Temper before the steel has cooled to below 100° C. Tempering temperatures are shown in the table, p. 172.

Temper No. 1 (0·60 per cent. carbon). Suitable for boilermakers' tools, hammers, miners' tools, etc.
Temper No. 2 (0·75 per cent. carbon). Suitable for chisels, sates, blacksmiths' tools, blades for cold shearing, etc.
Temper No. 3 (0·90 per cent. carbon). Suitable for cold chisels, blades for hot shearing, hot sates, taps, special miners' drills, etc.
Temper No. 4 (1·05 per cent. carbon). Suitable for large turning-tools, cutters, taps, reamers, drills, punches, blanking tools, etc.
Temper No. 5 (1·20 per cent. carbon). Suitable for lathe tools, drills, and small cutters.
Temper No. 6 (1·35 per cent. carbon). Suitable for extra-hard planing-, slotting-, and turning-tools, drills, etc.

To anneal, heat slowly and evenly to 700–800° C. and cool in the furnace. Cooling rate should not be more than 25° C. per hour down to approximately 550° C., after which cooling may be in air. Period at annealing temperature may be from 1 to 4 hours, with danger of oxidation, hence the advantage of bright annealing in a controlled atmosphere.

Heat Treatment of Permanent-magnet Steels.—Chromium- or tungsten-steel magnets are formed at temperatures between 760 and 980°, the average being about 870° C. Annealing for machining follows in the furnace down to 540° C., after which the steel should be taken out of the furnace and cooled in the air. Water-quenching magnet steels are rarely employed to-day. Ten minutes at the hardening temperature is usually sufficient for magnets. Magnets can seldom have their magnetic properties restored by heat treatment if heated above 100° C., and for this reason tempering temperature should not exceed 100° C.

Heat Treatment of Stainless and Heat-resisting Steels.—All stainless steels, whether martensitic, ferritic, or austenitic, should be preheated, before forging, to approximately 800° C., and heat must be allowed plenty of time to permeate the whole mass, which will take longer than for carbon steels. Straight chromium stainless steels should be forged quickly, with swift repeated blows, between 1150 and 900° C. Forging should never be carried on below 850° C. Do not overheat. Fully temper for machining (see chart, Fig. 1). Cold working strains must be eliminated by annealing at 750° C.

Soft chromium irons should not be forged below 900° C., and overheating must not occur. Forging temperature range is 1040–1150° C., but the lower temperature of 1090° C. is more suitable for most of these steels. Relieve forging stresses by annealing at 750–800° C.

Austenitic stainless steels (18–8 chromium-nickel) should be re-softened after work-hardening, if desired, by heating to about 1100° C. and thoroughly soaking at this temperature. Good softness may be obtained by heating to 1000° C. and cooling in air or water quenching from this temperature. Preheat to 815° C. for forging, and soak well. Do not continue forging below 900° C.

A heat-resisting steel containing approximately 12 per cent. chromium, 0·1 per cent. carbon, 0·5 per cent. manganese, 0·2 per cent. silicon will air harden from 970 to 995° C. A 17 per cent. chromium, 0·1 per cent. carbon, 0·5 per cent. manganese, 0·3 per cent. silicon steel may be slightly hardened by heating to 980° C. and air cooling. A 27 per cent. chromium, 0·15 per cent. carbon, 0·7 per cent. manganese, 0·3 per cent. silicon steel cannot be heat treated.

Austenitic heat-resisting steels may be partly heat treated. A 25 per cent. nickel, 0·25 per cent. carbon, 20 per cent. chromium, 0·6 per cent. manganese, 2·5 per cent. silicon steel may be forged at 1120–925° C., and fully softened at 1095–1150° C. Another steel, with 25 per cent. chromium, 12 per cent. nickel, 0·2 per cent. carbon, 0·75 per cent. silicon, 1 per cent. manganese, may be preheated to 845–870° C. for forging, forged at 1230–1095° C. (minimum forging temperature 985° C.), and softened by heating to 1090–1150° C., and cooled in

the furnace. A third steel, with 25 per cent. chromium, 20 per cent. nickel, 0·25 per cent. carbon, 1·1 per cent. silicon, and 0·6 per cent. manganese, may be pre-

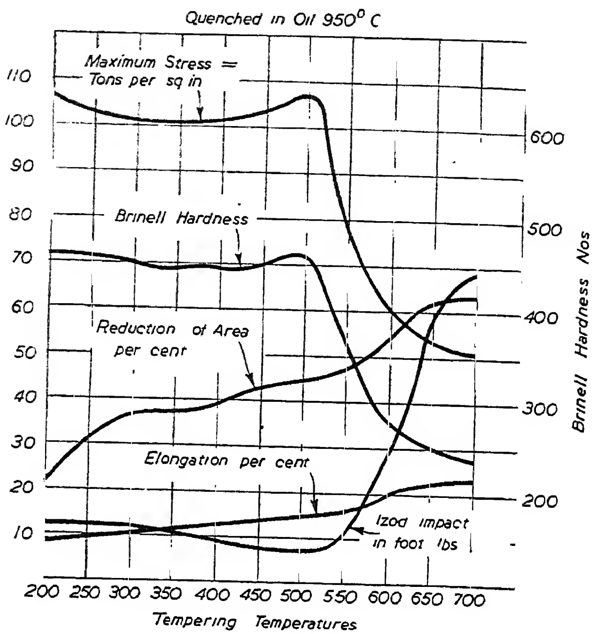


Fig. 1.—Tempering temperatures for stainless steel.

heated for forging at 925–980° C., forged at 1205–1120° C. (minimum forging temperature 980° C.), and softened by heating to 1095–1150° C.

HEAT TREATMENT OF ALLOY CHISEL STEELS

No.	Typical Composition							Forging Range °C.	Normalise °C.	Anneal °C.	Harden °C.	Temper °C.
	C	*Si*	*Mn*	*W*	*Cr*	*Va*	*Ni*					
1	0·45	0·3	0·3	1·9	1·8	0·2	—	1050–845	—	730	900–950	—
2	0·4	0·3	0·3	—	—	—	2·75	1000–870	850	730	900–950	—
3	0·4	0·3	0·3	2·0	—	—	—	1000–870	870	730	900–950	—
4	0·5	0·8	—	—	—	0·2	—	1095–870	900	775–790	—	—
5	0·6	—	—	—	0·5	—	—	1150–870	870	775–790	790–815	175–290
6	0·5	14·0	0·4	0·5 *Mo*		—	—	1065–870	870	790–815	855–915	175–370

If Steel No. 1 is used for cold dies, it should be tempered at 200–230° C. If used for hot dies, at 500–550° C. All except the last two steels should be quenched in oil, the exceptions being quenched in brine or water.

PERMANENT-MAGNET STEELS

Type of Steel	Analysis											Heat Treatment	Magnetic Properties		
	C	Si	Mn	W	Cr	Co	Ni	Al	Mo	Ti	Cu		Br (Gauss)	Hc (Oersted)	B–H (max.)
Carbon	0·90	0·20	0·35	—	—	—	—	—	—	—	—	W.Q. 760° C.; T. 200° C.	9,000	55	200,000
Tungsten	0·65	0·20	0·40	6·0	0·5	—	—	—	—	—	—	O.Q. 850° C.; T. 200° C.	10,000	70	260,000
Chrome-tungsten	0·95	0·15	1·10	4·0	5·0	—	—	—	—	—	—	O.Q. 800° C.; T. 250° C.	10,000	65	280,000
Cobalt-tungsten	0·90	0·20	0·40	9·0	3·0	15·0	—	—	—	—	—	O.Q. 900° C.; T. 300° C.	9,000	160	450,000
Chromium	1·00	0·15	0·40	—	6·0	—	—	—	—	—	—	O.Q. 480° C.; T. 250° C.	9,000	70	250,000
Cobalt-chromium	0·90	0·20	0·40	—	9·0	5·0	—	—	0·5	—	—	A.C. from 1150° C.; reheat to 700° C. and A.C.; reheat to 1000° C.; cool to 300° C. and O.Q.	7,500	145	450,000
	1·00	0·20	0·30	—	9·0	15·0	—	—	1·0	—	—		8,200	185	600,000
	0·95	0·20	0·30	5·0	—	35·0	—	—	0·5	—	—	O.Q. 930° C.	9,500	235	900,000
Nickel-aluminium[1]	0·08	0·60	0·30	—	—	—	27·0	12·5	—	0·25	3·50	A.C. 1200° C.; T. 650° C.	8,000	450	1,750,000
Nickel-cobalt-titanium	0·05	—	—	—	—	25·0	25·0	0·25	—	12·00	—	As cast	6,500	800	—

W.Q. = water quench; O.Q. = oil quench; A.C. = air cool; T. = temper.

[1] Alloys of this type are also placed into service as castings; to get the best magnetic tests the rate of cooling after casting is then modified to suit the cross-sectional area.

Heat Treatment of Die Steels

Typical Composition								Forging Range ° C.	Normalise ° C.	Anneal ° C.	Harden ° C.	Temper ° C.
C	Mn	Si	W	Cr	Va	Mo	Co					
1·0	0·95	0·3	0·4	0·75	—	—	—	1000–700	840–860	730	780–800	200–250
0·9	1·1	0·3	0·5	0·5	0·2	—	—	1065–870	900	775–790	790–815	165–260
0·9	1·6	0·3	—	—	—	—	—	1040–870	845	760–775	760–800	165–260
1·15	0·3	—	1·6	0·5	0·2	—	—	1065–870	925	790–800	855–885	175–290
1·65	0·25	0·3	—	12·5	0·35	0·85	—	1100–870	950–980	780–800	950–1050	200–250
1·3	0·25	0·3	—	12·5	—	1·25	2·5	1050–870	950–980	780–800	950–1050	200–250
2·1	0·25	0·3	—	12·0	0·5	—	0·5	1040–870	—	870–900	970–995	205–510
0·3	0·25	0·3	9·5	3·25	0·35	—	—	1150–900	—	800	1100–1150	600–700
1·05	0·25	0·3	—	4·0	—	—	—	1100–900	—	750–770	900–1050	445–665
0·6	0·65	—	—	0·75	—	0·25	—	1065–845	870	760–790	870–900	315–540
0·6	—	—	—	4·0	—	0·5	—	1065–870	—	790–815	885–980	315–595
0·35	—	1·0	—	5·0	0·4	1·4	—	1150–900	—	815–845	980	540–650
0·5	—	—	2·0	1·25	0·25	—	—	1065–845	—	790–815	900–955	175–675
0·4	0·6	1·5	7·5	7·5	—	—	—	1150–925	—	870–900	1120–1175	315–540
0·35	0·25	1·2	4·65	5·0	—	0·45	—	1000–850	—	750	950	550
0·45	0·6	0·3	—	1·75	0·2	—	—	1000–850	—	730	850	500
0·45	0·7	—	—	0·8	1·25 Ni		—	1065–845	870	760–790	815–845	260–425
0·3	0·5	—	—	1·2	*Va*	0·5	1·2 *Al*	1150–870	—	—	*Nitride*	—
0·3	—	0·9	1·0	5·0	0·25	1·0	0·5	1150–900	—	845–870	980–1010	540–595
0·3	0·6	0·9	—	5·0	0·25	1·0	—	1150–900	—	845–870	980–1010	540–595
0·35	—	—	10·0	3·0	0·5	—	—	1175–900	—	870–900	1010–1175	540–655

This table does not include plain carbon die steels. The first four steels should be hardened in oil. Some of the remaining steels may be hardened in the air blast. In general, the lower temperatures represent the oil hardening; the higher, the air hardening. All the first four steels should be preheated for hardening at 650° C. For the other steels, the preheating temperature range is 750–845° C. It is always advisable to consult the maker of the individual die steel for precise heat-treatment temperatures, as slight differences in composition affect treatment temperatures. Preheating minimises shrinkage and distortion and produces maximum hardness-cum-toughness. Gradual and uniform heating is recommended.


ON TOP OF THE WORLD
MACROME

HEAT TREATMENT OF HIGH-SPEED STEELS

Typical Composition								*Forging Range* °*C.*	*Harden* °*C.*	*Secondary Harden* °*C.*	*Anneal* °*C.*
C	*Si*	*Mn*	*W*	*Cr*	*Va*	*Co*	*Mo*				
0·8	0·3	0·25	21·0	5·0	1·4	11·5	0·4	1200–980	1380–1400	580–600	900–950
0·8	0·3	0·25	19·0	5·0	1·4	5·5	0·4	1175–955	1350–1380	580–600	900–950
0·75	—	—	14·0	4·0	2·0	5·0	0·5	1175–925	1275–1300	540–620	870–900
0·8	—	—	20·0	4·0	2·0	8·0	0·6	1205–980	1275–1300	540–620	870–900
0·75	0·3	0·25	19·0	4·5	1·4	—	—	1150–925	1280–1330	580–600	850
0·65	0·3	0·25	15·0	3·5	0·5	—	—	1150–925	1250–1300	580–600	850
0·8	—	—	18·0	4·0	2·0	—	0·7	1200–925	1260–1290	540–620	870–900
—	—	—	6·0	4·5	1·35	—	5·5	1100–900	1250–1300	560 for 45 m. twice, or 560 for 90 m.	820–840
0·8	—	—	1·5	4·0	1·0	—	9·0	1095–900	1175–1230	510–595	845–870
0·8	—	—	—	4·0	2·0	—	9·0	1095–900	1175–1230	510–595	845–870
0·8	—	—	1·5	4·0	—	5·0	9·0	1095–900	1200–1230	510–595	845–870

Cobalt high-speed steels should be reheated, after forging, to 900–950° C., to relieve strains. Gradual cooling in lime or mica after forging will be found beneficial. Preheating of all high-speed steels before hardening is advisable. The temperature range is 760–870° C., but the precise temperature depends on the type of steel, and as slight modifications in composition affect heat treatments, it will be as well to take the advice of the manufacturer of the particular high-speed steel used. For high-speed steels, a controlled atmosphere furnace with a carefully calibrated pyrometer is always recommended. Where tools are of considerable mass, a double preheating, at 620–700° and 870–925° C., may be found beneficial. Avoid burning the tool nose. Secondary hardness treatment is essential for the cobalt high-speed steels. Do not allow the steel to cool below 40° C. from the quenching temperature. The tools should not be placed in a cold furnace. A salt bath or a gas-fired furnace with a reducing flame is required for hardening the cutting edges of milling cutters. Painting with a silica paint gives additional protection. Avoid too rapid preheating of complicated or delicate tools.

A further annealing after machining may be advantageous for special-form tools, and this should be carried out at 650–730° C. Forged steels and tools should be rough ground after forging and annealing to eliminate oxidation scale and decarburised skin. To straighten a slightly distorted tool, carry out the work while the tool is at a temperature between 580 and 230° C. Do not attempt to straighten if temperature has fallen to below 230° C.

Molybdenum high-speed steels, until recently used in this country as alternatives to high-tungsten high-speed steels, and still so used in the United States, are liable to decarburise, and must be forged at lower temperatures. Tempering and hardening temperatures must also be lower than those of the tungsten steels to which they correspond. These steels must be held in the furnace for only the briefest possible period at the maximum forging temperature. Slow cooling in ashes, lime, or mica is beneficial in preventing stress cracks. Reheat after forging to 820–840° C. for normal annealing. Large sections must be preheated carefully to 600–800° C. before being placed in a hot furnace. Reheating to 650–730° C. after machining relieves machining strains. Quenching may be in either oil or a strong, dry, fan-generated air blast. Temper *immediately* after hardening for 45 minutes at 560° C. (This is most important.) Retempering for a similar period at the same temperature is beneficial, and essential for tools subject to shock. Alternatively, temper at 560° C. for 90 minutes.

HEAT TREATMENT OF SPECIAL STEELS

	Typical Composition								Purpose
	C	*Si*	*Mn*	*W*	*Cr*	*Mo*	*Ni*	*Va*	
(a)	1·25	0·3	0·25	3·75	0·5	—	—	—	Machining brass and chilled iron rolls.
(b)	0·3	0·3	0·6	—	1·05	—	—	0·2	Rivet snaps, etc.
(c)	1·5	—	—	—	12·0	0·75	—	—	Thread rolling dies.
(d)	0·6	—	0·6	—	0·9	0·7	1·75	—	Die blocks.
(e)	0·35	—	—	10·0	3·0	—	—	0·5	Die inserts.
(f)	0·6	—	0·6	—	1·0	0·5	1·5	—	Solid shear blades.
(g)	0·5	—	—	—	0·8	—	—	0·2	Hot rivet sets.
(h)	1·15	—	0·3	1·6	0·5	—	—	0·2	Screwing taps, etc.
(i)	0·45	0·25	0·6	—	1·05	—	—	0·2	Plastic moulds.
(j)	1·2	0·5	12·0	—	—	—	—	—	Wearing parts of crushers, etc.
(k)	0·4	0·25	0·6	—	1·05	—	—	0·15	Coalcutter picks.

	Forging Range ° *C.*	*Normalise* ° *C.*	*Anneal* ° *C.*	*Harden* ° *C.*	*In*	*Temper* ° *C.*
(a)	1000–790	—	730	820– 840	W.	150–180
(b)	1050–850	—	730	830– 850	W.	200 for 1½–2 hrs.
(c)	1065–980	—	870–900	925– 980	O.	205–540 2½ hrs. min.
(d)	1065–845	870	760–775	815– 855	O.	315–595
(e)	1175–900	—	870–900	1010–1175	A. or O.	540–675
(f)	1065–845	790	760–775	845– 885	O.	315–540
(g)	1095–815	790	775–790	{ 775– 790 900– 955	O. O.	150–290 230–315
(h)	1065–870	925	790–805	855– 885	O.	175–290
(i)	1050–850	—	730	850	O.	200
(j)	1000–760	—	—	950–1000	W.	—
(k)	1050–850	—	730	800 (½ in. up point only)	W.	—

(*c*) should be preheated for hardening to 815° C. and (*e*) to 815–855° C. The two hardening and tempering treatments given for (*g*) are alternatives.

Mass Effect in Heat Treatment.—The greater the mass or cross-sectional area of a forging, the lower its tensile strength and elastic limit for a specific heat treatment, but the higher its ductility or plasticity. The larger the mass the more difficult complete hardening becomes. If alloy steels are not employed, the alloys counteracting this effect of mass, the heat treatment of the piece must be modified to allow for mass effect. This comprises, as a rule, modified quenching and tempering temperatures.

HEATING PERIOD FOR CARBON-STEEL FORGINGS, ETC.

Carbon Content per cent.	*Bar Section*	*Correct Heating Period*
0·1–0·5	½–3 in.	5–6 mins. per in. of diam. or thickness.
0·5 and over	3 in. and over	6 mins. and over per in. of diam. or thickness.

It should be noted that some metallurgists advise even longer heating periods.

Overheating of Steels.—Overheating is not the same as burning. Burnt steels are useless. Overheated steels may often be reclaimed by heat treatment. Overheating sets up grain enlargement, causing reduced mechanical strength. It is usually caused by too high a heating temperature or by the direct impingement of a furnace flame on the steel. It may thus be either general or local. Burning partly fuses the steel. The liquefied ingredients travel in the direction of the grain boundaries and, having little cohesion, cause the steel to disintegrate readily as soon as it is subjected to hot or cold manipulation. To restore the structure of an overheated steel, reheating to and cooling from the correct temperatures for the particular steel, i.e. to a temperature just beyond its upper critical point, will suffice. Burnt steels are not restored by this or any other treatment.

Spheroidising.—Heating steels in such a way that the cementite existing with ferrite in the pearlitic form becomes present as small spheroids or globules. This lowers the hardness of a carbon steel, but increases its machinability. By heating a pearlitic steel to a temperature just below the Ac_1 point (about 1250–1300° C.), or alternatively slightly above this point but for a longer period, this spheroidisation is obtained. Spheroidising improves grain structure and minimises quenching cracks, as well as yielding a more even hardness.

Austempering.—Raising a steel's temperature until it is austenitic in structure, then p unging it into a lead bath or salt bath held strictly at a predetermined temperature and so producing a cooling rate slow enough to stop the steel from arriving at the hard, martensitic structure. The temperature of the bath is below the change point, but too high for full quenching. A tougher steel for a specific hardness is thus obtained than is feasible with ordinary hardening and tempering. As a rule the process is not applied to steels more than ½ in. in thickness, nor to steels outside the range 0·5–1·2 per cent. carbon. The temperature range is 315–540° C., the exact temperature being largely governed by carbon content, the higher temperatures corresponding to higher carbon content. Mostly the process has been applied to shovels, but it may soon be adopted for case-hardening steels and for small springs.

Temperature Gradient.—The rate of variation in the temperature of a metal over a given unit distance, i.e. the difference in the speed with which the metal cools at one point of its mass as compared with another. It affects design of parts and also the quenching medium adopted.

METALLURGY

Acid Steel.—Steel made in a furnace lined with silica bricks, white sand, or ganister.

Ageing.—A spontaneous change in the properties of metals. It may take place at normal temperatures or when the metal is slightly heated, either after the last heat treatment (quenching, as a rule), or after the last cold-working operation.

Allotropic Modifications.—The different forms in which an element may exist.

Alpha Iron.—Iron below 768° C.

Annealing.—Softening steel by heating it to a suitable temperature. Annealing makes hard steels machinable, and also relieves internal stresses earlier produced by hot working.

Arrest Points.—See "Critical Points."

Austenite.—The solid solution of iron carbide in gamma iron.

Basic Steel.—Steel made in a furnace lined with burnt dolomite.

Bath.—The molten metal or salt in a heated receptacle.

Beta Iron.—Iron between 900 and 768° C.

Blister Steel.—Steel made from pig iron by cementation, and covered with small blisters.

Blowholes.—Gas-containing cavities in steel, etc.

Body-centred Cubic Lattice.—A space-lattice diagram in which there is an atom at each corner and also one in the centre of each cube.

Brinell Test.—Testing steel's hardness by forcing a small hardened and tempered chromium-steel or tungsten-carbide ball of specific size under controlled pressure into the steel to be tested.

Carbide of Iron.—A compound of iron with carbon, intensely hard.

Case-hardening.—Giving steel a very hard external skin or case by burying it in a highly carbonaceous material and heating it to a suitable temperature for a prolonged period.

Castings.—Parts manufactured by teeming molten metal into a formed mould.

Cast Tool Steel.—Tool steel made by the high-frequency or crucible process.

Caustic Embrittlement.—A fault mostly found in steel pressure vessels when the metal is subjected to high and continuous stresses in the presence of a strong alkaline solution. Intercrystalline cracks are formed.

Cementation.—Introducing a pre-established amount of carbon into bar iron to produce blister steel.

Cementite.—Carbide of iron.

Charge.—The total amount of metal dealt with at one time in a furnace or converter.

Cleavage Planes.—The sets of parallel planes in which the atoms of a crystal are locatec.

Compound.—The chemical combination of two substances, which combination has properties different from those of either substance taken singly.

Compression Strength.—A steel's power of withstanding a compressive force developed by a specific load placed upon it.

Concentration.—The oxidation and removal of carbon, silicon, and manganese from a furnace charge, as well as some iron, which passes into the slag.

Converter.—A pear-shaped vessel in which steel is made by blowing air mechanically through liquid pig iron.

Corrosion Fatigue.—A fatigue crack formed in steel subjected to fluctuating or alternating stresses and placed within the influence of a corrosive agent. The corrosive attack develops most powerfully in the area of localised stresses, and eventually produces conditions favourable to the formation of fatigue cracks.

Critical Points.—Important temperatures on inverse-rate cooling curves indicating where vital changes of structure take place.

Crystal.—See "Grain."

Cupola.—The furnace in which pig iron to be made into steel is first melted.

Decalescence.—The sudden decline in heat at a certain point in the heating of steel.

Delta Iron.—Iron between its freezing-point and 1404° C.

Dendrites.—Tree-like aggregations of crystals formed as steel solidifies.

Deoxidant.—A material added to molten steel in the ladle to remove undesired oxygen.

Dilatometric Test.—A test indicating the volume changes occurring in a heated or cooled steel.

Elastic Limit.—The point at which steel loses all elasticity under increasing stress.

Electrode.—The pole or terminal point conveying the electric current in an electric-arc steel-melting furnace, or in a "submerged arc" resistance furnace.

Elongation.—The percentile extent to which a steel lengthens under a specific stress or load in the tensile test.

Equilibrium Diagram.—A means of diagrammatically indicating the changes in structure in a steel that correspond to changes in temperature.

Etching.—Treating a metal with chemical reagents to show up the various structural constituents.

Eutectic.—The mechanical mixture of two solid phases or conditions of a substance when composition and freezing temperature are fixed and invariable.

Eutectoid.—A substance similar to a eutectic, but formed wholly from solid solutions instead of from a liquid solution.

Face-centred Cubic Lattice.—A space-lattice diagram in which, besides one atom at each corner, there is also one atom at the centre of each face of the cube.

Fatigue Tests.—Tests determining a metal's ability to withstand repeated stresses.

Ferrite.—Virtually pure iron precipitated during the cooling of steels containing less than 0·85 per cent. carbon.

Flow Lines.—The lines along which metal has flowed under pressure, as revealed under the microscope.

Flux.—A substance added to molten metal to combine with impurities and cause them to pass into the slag.

Free-cutting Steels.—Steels of low carbon content designed for easy machining. They may be high in sulphur, or, if of stainless type, may have a selenium, bismuth, or silver content.

Gamma Iron.—Iron between 1404 and 900° C.

Grain.—The irregularly shaped small cubic cells or structural units of a metal as revealed by the microscope.

Graphite.—The free, i.e. uncompounded, carbon existing in cast iron. Also used for making electrodes.

High-speed Steel.—A highly alloyed tool steel for tools used in machines for cutting metals, etc.

Homogeneous.—Of a metal, uniform in character or consistent throughout its mass in some particular property.

Inclusions.—Non-metallic matter trapped in steel as it solidifies.

Inverse-rate Curve.—A cooling curve or graph correlating temperature with a material's structural changes.

Izod Impact Test.—A means of testing steel's ability to withstand impact and shock.

Killing.—Preventing the release of gases when molten steel solidifies.

Ladle.—A large bucket or receptacle for molten metal.

Macrography.—The examination of metallic structure, either visually or at extremely low magnification.

Magnetite.—Magnetic iron ore.

Martensite.—An extremely hard, needle-shaped constituent of steel formed when it is quenched from temperatures above its upper critical point.

Malleable Iron.—Wrought iron.

Mild Steel.—Steel of low carbon content.

Nitrided Steels.—Steels with an intensely hard, abrasion-resisting external case produced by the introduction of nitrogen into the surface layers of certain special steels.

Normalising.—Refining the structure of a metal by heating it to a suitable temperature and allowing it to cool *in the air.*

Occlusions.—Particles of slag trapped in steel when poured into moulds.

Open-hearth Steel.—Steel, purified by oxidation and removal of impurities, made from molten iron lying in the hearth of a special furnace.

Orientation.—That effect in crystals in which each individual crystal has the axes of the small cubes all pointing the same way, but in different directions from one crystal to another.

Pearlite.—A mechanical mixture or eutectoid comprising cementite and ferrite in definite proportions.

Phase.—A term frequently employed to indicate the particular structural condition of a metal at a specified moment, e.g. solid or liquid phase.

Photomicrographs.—Photographs of microscopically magnified steel specimens indicating structures and constituents.

Pig Iron.—Iron made in pigs by the blast furnace.

Precipitation.—The throwing out of solution of dissolved particles when, owing to a change in the conditions, that solution can no longer retain them as dissolved.

Puddling.—A process for producing a very pure wrought iron from molten pig iron by removing the oxides in a special furnace.

Recalescence.—The sudden evolution of heat at a certain point in the cooling of steel.

Reduction.—The elimination of oxygen from a molten metal.

Reduction of Area.—The percentage of the original cross section of a steel specimen represented by the fractured cross section after the execution of the tensile test.

Red Hardness.—The cutting efficiency of a steel at high temperatures.

Rimming Steel.—Low-carbon steel of the semi-killed type containing gas cavities but practically no pipe. The blowholes close up when the metal is hot rolled.

Rokes.—See "Seams."

Saturated Solution.—One in which as much of a substance is dissolved in a liquid as the liquid will absorb.

Seams.—Internal discontinuities in a metal caused by blowholes.

Segregation.—The concentration of impurities in certain zones in metallic ingots and the smaller sections made from them.

Shearing Tests.—Tests undertaken to determine the power of a steel or other metal to withstand a shearing action.

Slag.—The scum that forms, or is deliberately fostered and specially composed, on the surface of a molten metal, then skimmed off to remove impurities.

Soaking.—Complete penetration of a mass of metal by heat.

Solid Solution.—The condition of steel in which, as a result of raising the temperature, the iron carbide dissolves in the iron.

Sorbite.—The constituent produced in hardened and fully tempered steels; it is made up of tiny particles of iron carbide evenly dispersed throughout the ferrite matrix. It may also be formed by cooling steel more slowly than is necessary for the formation of troostite, as in large masses cooled in air or oil.

Space Lattice.—The arrangement or spacing of atoms, represented in diagrammatic form.

Tempering.—Reheating steel to a temperature below its lower critical point, to reduce the brittleness caused by hardening.

Tensile Strength.—A metal's ability to withstand a specific pulling stress.

Thermal Hysteresis or Lag.—The difference between the arrest or critical points when steel is heated and when it is cooled.

Time-temperature Curve.—A curve or graph in which time is correlated with temperature.

Torsion Test.—A test revealing a metal's ability to withstand twisting stresses.

Troostite.—A transitional constituent in steel arising out of the breakdown of austenite into pearlite, but formed at a much higher temperature than martensite.

Tuyères.—Pipes introducing the air blast into the Bessemer or Tropenas converter, etc.

White Cast Iron.—Cast iron with more than 1·8 per cent. carbon (as carbide).

Wrought Iron.—Iron produced from molten pig iron by a working or puddling process. It is malleable.

Yield Point.—That point at which, when a metal is stretched in the tensile test, there is a sudden very great elongation (or strain increase) produced by a very small increase of the load.

Corrosion-resisting Steels.—Stainless steels were originally discovered in 1913. There are broadly two main classifications, the straight chromium steels, containing 12–14 per cent. chromium, and the austenitic nickel-chromium (18/8) stainless steels, containing approximately 18 per cent. chromium, 8 per cent. nickel. When the carbon percentage of the straight chromium steels is reduced, the chromium percentage is also reducible, and there is thus produced a range of "stainless irons," which are malleable and have their special field of use. The principal difference between the various types of stainless steels used in modern engineering lies in the kind and percentage of alloying elements introduced to give specific properties to the basic stainless-steel compositions. These alloys include nickel, silicon, molybdenum, titanium, tungsten, niobium (columbium), selenium, bismuth, and silver.

The austenitic nickel-chromium stainless steels (18 per cent. chromium, 8 per cent. nickel) are liable to work-hardening, and demand special technique or alloying for machining, etc., but are resistant to most acids and other corrosive agencies. Qualities suitable for deep stamping can be obtained, as well as free-machining qualities.

Stellite.—Stellite is a non-ferrous alloy of cobalt, chromium, and tungsten, and possesses a greater cutting power than even high-speed steel. Tools are usually tipped with it, the tips being brazed or welded on to steel shanks. Some smaller-sectioned tools are supplied as solid stellite tools. The material may also be applied straight on to the shanks by melting it with an oxy-acetylene flame without flux.

Free-cutting Steels.—For quick machining in automatic machines, steels have to be more readily machinable than usual. A suitable free-cutting mild steel of British manufacture contains 0·4–0·5 per cent. sulphur. Phosphorus up to 0·1 per cent. is permissible. Where these high-sulphur steels are used, the manganese to sulphur ratio must be greater than 2, to prevent hot and cold "shortness," i.e. brittleness. Phosphorus should be kept as low as possible.

Lead has of late years been introduced into steels of normal sulphur content to improve machinability, and in this has been highly successful. There is no advantage, however, in adding it to steels high in sulphur, though the makers of the leaded steels do not necessarily agree with this view. Incidentally, the latter steels attain their maximum machinability only when bright drawn. Stainless austenitic nickel-chromium steels are being produced with additions of selenium, or bismuth, to improve their machinability. Selenium is, so far, the most popular element for this purpose, but bismuth is believed to hold out high promise. Silver in very small percentages has also been used for free-machining stainless steels, but the first claims for this do not appear to have been fully justified.

Alloys in Steel—Their Effects

Silicon.—Raises the critical points. In silicon steels, gives a low magnetic hysteresis, so that magnetic losses are minimised. Gives ability to withstand high temperatures. May also, in suitable percentages, give toughness and fatigue resistance.

Manganese.—Lowers the critical points. Above 2·0 per cent. gives air-hardening properties; 12–14 per cent. gives a highly wear-resistant steel that may be bent cold without fracture.

Nickel.—Lowers all the critical points. Produces fine grain, often synonymous with toughness. Confers greater strength without loss of ductility. Renders steel highly susceptible to heat treatment.

Chromium.—Raises the critical points. Confers a high degree of corrosion resistance, particularly if used in percentages from 12 to 14. Up to 1 per cent. raises the tensile strength without reducing ductility. Gives greater wear resistance and abrasion resistance. Increases brittleness.

Vanadium.—Improves ability to withstand a measure of overheating. Acts as an oxide remover. Improves cutting qualities of tools. Over 2 per cent. makes steel brittle and hard.

Molybdenum.—Refines grain. Improves resistance to impact or shock after hardening and tempering. May be used to replace tungsten in cutting-tool steels. Up to 2 per cent. gives greater hardness and cutting power so long as vanadium is also present.

Tungsten.—Improves grain size. Gives red hardness to tool steels, i.e. power of cutting while at red heat. Raises critical points. Confers air-hardening properties.

Cobalt.—Improves magnetic properties. Raises coercive force in magnet steels, and slightly increases remanence. Gives greater cutting power to high-speed tool steels. Increases hardness and brittleness.

WELD DECAY

Austenitic stainless steel of 18/8 type is extremely susceptible to corrosive attack by liquids after it has been reheated to 600–900° C. The attack occurs along the crystal boundaries, and is known as "weld decay," having been first

LINEAR EXPANSION COEFFICIENTS FOR 1° C. (MULTIPLIED BY 10^6)

Material	Temperature ° C.										
	20–100	20–200	20–300	20–400	20–500	20–600	100–200	200–300	300–400	400–500	500–600
Aluminium, Cast	23·8	24·7	25·7	26·7	27·7	28·7	25·5	27·5	29·5	31·5	33·5
Antimony	10·5	—	—	—	—	—	—	—	—	—	—
Arsenic	5·0	—	—	—	—	—	—	—	—	—	—
Bismuth	13·2	—	—	—	—	—	—	—	—	—	—
Brass	17·8–19·8	18·5–20·5	19·1–21·2	19·8–21·8	20·5–22·5	—	—	—	—	—	—
Bronze (Al), Cast	17·6	17·9	19·2	—	—	—	—	—	—	—	—
Bronze (Pb), Cast	19·1	19·2	19·4	19·5	19·6	—	—	—	—	—	—
Bronze (Mn), Cast	20·0	20·4	20·8	21·6	22·7	—	—	—	—	—	—
Bronze (Ni), Cast	17·3	17·7	18·1	18·4	18·8	—	—	—	—	—	—
Bronze, Phos., Cast	18·1	18·4	18·8	19·1	19·4	—	—	—	—	—	—
Cadmium	31·6	—	—	—	—	—	—	—	—	—	—
Cobalt	12·36	—	—	—	—	—	—	—	—	—	—
Copper, Rolled	16·6	17·1	17·6	18·1	18·6	—	—	—	—	—	—
Duralumin	23·8	24·7	25·7	26·3	27·2	—	—	—	—	—	—
Gold	13·8	—	—	—	—	—	—	—	—	—	—
Graphite	7·86	—	—	—	—	—	—	—	—	—	—
Gunmetal, Cast	18·7	19·1	19·6	20·0	20·4	—	—	—	—	—	—
Lead	27·09	—	—	—	—	—	—	—	—	—	—
Magnesium	25·8	—	—	—	—	—	—	—	—	—	—
Monel, Rolled	13·5–13·9	14·1–14·4	14·7–14·9	15·3–15·5	15·9–16·0	—	—	—	—	—	—
Munk Metal	19·5	20·3	21·0	28·0	—	—	—	—	—	—	—
Nickel	13·1	13·8	—	—	—	15·5	13·5	14·8	17·2	16·6	17·1
Nichrome	12·4	13·0	13·6	14·1	14·7	—	—	—	—	—	—
Palladium	11·76	—	—	—	—	—	—	—	—	—	—
Platinum	8·99	—	—	—	—	—	—	—	—	—	—
Silicon	7·63	—	—	—	—	—	—	—	—	—	—
Silver	19·21	—	—	—	—	—	—	—	—	—	—
Silver Solders	19·0	19·2	19·6	20·4	21·3	—	—	—	—	—	—
Tantalum	6·5	—	—	—	—	—	—	—	—	—	—
Tin	22·95	—	—	—	—	—	—	—	—	—	—
Tungsten	4·3	4·4	4·5	4·5	4·6	—	4·5	4·6	4·7	4·8	—
Zinc	29·76	—	—	—	—	—	—	—	—	—	—

observed in welded parts. To prevent it as far as possible, carbon content of the steel must be kept as low as possible. Slight increases in chromium and nickel contents are also useful. If it can be carried out, a heating of the steel to 1100° C., followed by cooling in the air or by air blast (preferable), will prevent this form of corrosion. Otherwise silicon, tungsten, copper, titanium, or columbium (niobium) may be added to the composition to eliminate the need for final heat treatment after welding. Columbium appears to be the most satisfactory addition for this purpose.

Sulphur Prints.—Steep a sheet of bromide paper thoroughly in 5 per cent. dilute sulphuric acid, and lay on to the polished prepared surface. Squeeze out air bubbles with a rubbered roller. Leave long enough for the necessary chemical reactions to take place, then peel off, wash with water, and fix in hypo solution.

The Iron-carbon Diagram.—The iron-carbon equilibrium diagram (Fig. 2) should actually be termed iron-cementite equilibrium diagram. It is designed to show the structural changes in carbon steels when slowly heated or cooled. The solutions known as " steels " occur within the field containing less than 1·7 per cent. carbon. As soon as molten steel cools to a temperature that falls on the

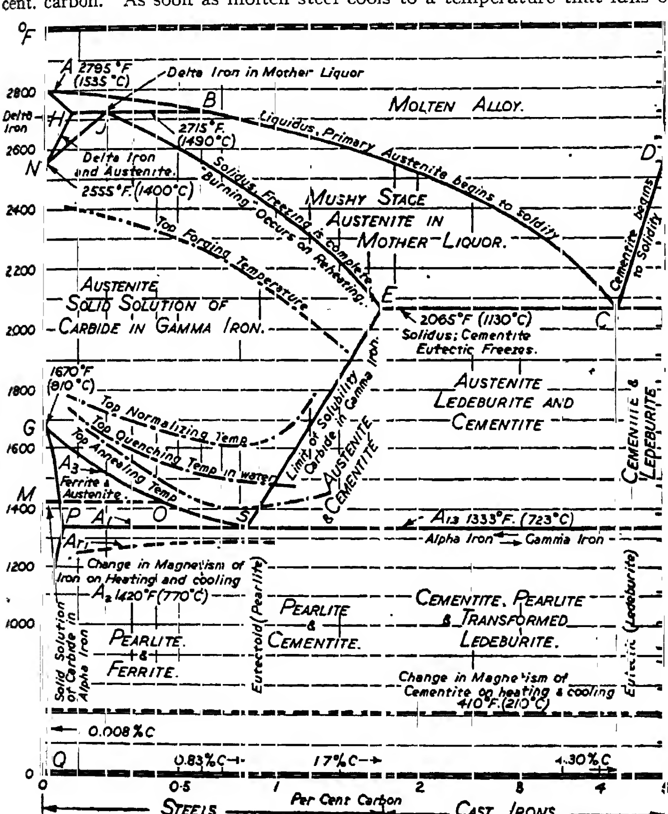


Fig. 2.—Iron-carbon equilibrium diagram.

line ABC, a solid phase starts to appear as crystallites. The solidification continues with declining temperature, until at the end the steel is entirely solid. When steels have a carbon content below approximately 0·55 per cent. carbon, the delta phase is formed straight from the molten condition, but as the whole of the delta phase changes to the gamma phase or austenite on passing through the line NJ, the delta phase may in practice be ignored, and it can therefore be assumed that austenite is formed straight from the molten metal even when the steel is extremely low in carbon percentage.

Austenite is a solid solution of carbon in gamma iron, and is stable only at high temperatures in most tool steels. Its atoms are built up on a face-centred cubic space lattice.

As soon as it has become solid, the steel is made up of homogeneous austenite, i.e. all the carbon has gone into solid solution. The line JE (or, accurately, NHJE) is of great metallurgical importance, for the reason that it indicates the maximum temperatures to which a steel may be heated without beginning to melt. The sharp fall of the line JE indicates that the highest permissible heating temperature for forging quickly falls in inverse ratio to the carbon percentage of the steel. That is why steels of high carbon content are harder to weld by the forge hammer than steels of low carbon content.

Steels are divisible into hypo-eutectoid, eutectoid, and hyper-eutectoid. The eutectoid composition includes steels with 0·83–0·9 per cent. carbon. Hypo-eutectoid steels contain less carbon than this; hyper-eutectoid contain more. The iron-carbon diagram must not be employed to ascertain the proper heat-treatment temperatures for alloy steels. These can be decided only by experience or by reference to equilibrium diagrams of more complicated type referring specifically to the alloy system concerned.

Hot-acid Etching.—A highly specialised test applied mostly to blooms and billets as a check on manufacture. Cross-sectional discs varying from $\frac{1}{2}$ to 1 in. thick are mainly employed. The disc should have a very smooth face, and if the cutting-off operation does not produce this, the face must be ground. The specimen is plunged in a hot HCl (1·08 per cent. specific gravity) solution. Time left in the solution depends on composition of steel, size of test-pieces, etc. Carbon steels need a briefer immersion period than alloy steels. Time ranges usually from 30 to 45 minutes. The test, if correctly carried out, gives valuable insight into the steel's internal structure.

Units Employed in Measurement of Permanent Magnets.—Small magnets are mostly magnetised directly by the pole pieces of a large electromagnet. Heavier sections are placed inside a solenoid, and as a rule a special coil is wound to suit the form of the magnet.

Magnetomotive force is measured in the c.g.s. system by a unit termed a *gilbert*, which is expressed by the equation $F = 0{\cdot}4\pi NI$, where F is the magnetomotive force in gilberts, N is the number of turns on the solenoid, and I is the current in amperes.

The unit of magnetic flux is termed the *maxwell*, and its magnitude is such that when the flux cut by a single turn of wire varies at the rate of 100,000,000 maxwells per second, a potential of 1 volt is picked up by the wire.

The *gauss* is the unit of magnetic induction and represents the magnetic flux density across any section normal to the direction of flux. Across any section where the flux is evenly distributed, the magnetic induction is calculable by the equation $B = \frac{M}{S}$, where B is the induction in gausses, M the flux in maxwells, and S the area of section in square centimetres.

In a magnetic circuit the useful magnetic flux is limited by the reluctance or resistance of that circuit. The *œrsted* is the unit of magnetic reluctance, and is defined by Ohm's law of magnetic circuits. $O = \frac{G}{M}$, where O is œrsteds, G is gilberts, and M is maxwells.

Magnetic permeability is the ratio of magnetic induction to its corresponding magnetising force, and is represented by the equation $P = \frac{G}{O}$, where P is permeability, G is gausses, and O is œrsteds.

Residual induction is measured in gausses, and comprises the magnetic induction remaining in a piece of magnet steel after the magnetising force has been brought down to nil.

Coercive force is measured in œrsteds, and comprises the reversed magnetising force just adequate to bring the residual induction down to 0.

Penetration Fracture Test.—A test for ascertaining the hardening properties of a carbon tool steel. Round test-pieces of specific diameter and length are used, and hardened under uniform conditions in a brine stream. The test-pieces are heated and quenched from normal and from an arbitrary series of higher temperatures at pre-established temperature intervals. After being quenched, the test-piece is cut transversely and etched to show the depth of hardened layer. It is fractured transversely to enable the fracture to be graded according to grain size. Depth of hardness penetration (P) is recorded as the numerator of the fraction that expresses in sixty-fourths of an inch the depth of hardened layer on the etched specimens. Grain size (F) is measured by visual comparison with an empirical set of standards made from martensitic steel fractures.

Heating Steel.—Cracking, burning, and decarburisation are the dangers. On being heated, steel expands at a virtually constant rate up to its critical temperature range. This is termed the coefficient of linear expansion. On the steel's attaining the critical or Ac range, expansion ceases, and actually contraction begins in spite of the continued increase in temperature. When the change of structure is completed, expansion begins again. These alterations of volume are reversed when the steel is cooled, the critical transformation point being depressed.

Steel at high temperatures is not so strong as the same steel when cold or at room temperature. The higher the heating temperature, the closer the steel comes to the " blue brittleness " range. Up to this point its strength has steadily declined, but now it increases, even in some instances attaining its original figure. As soon as the region of " blue brittleness " is left behind, however, the strength once more declines. At 870° C. tool steel will show 10,000–40,000 lb. per square inch tensile strength.

Cracking is the result mainly of too quick a heating or cooling or uneven heating and cooling. This means that the volume of one part of the mass changes more rapidly than that of the rest, and in consequence stresses are set up that exceed the power of the steel to withstand them. The harder the structural constituents of the steel, the greater the likelihood of cracks. Higher carbon content usually means greater risk of cracking, as will be seen by a glance at the iron-cementite equilibrium diagram shown on page 195.

Decarburisation is caused by raising the temperature of the steel to a point at which in an ordinary furnace scaling occurs, or, in other furnaces, when a smoky flame is produced. The extent of decarburisation is governed by time and temperature, and is likely to be greater with high-carbon than with low-carbon steels.

Machining Hardened Steels.—Whenever a steel tool or other part has been subjected to a hot manipulating process, e.g. forging or rolling, scaling and decarburisation occur. The scale and soft skin must, therefore, be machined off before the tool is used. Up to 1-in. section, a machining allowance of $\frac{1}{32}$ in. minimum per side must be made, and even more if the parts are long. For tools over 1-in. section, $\frac{1}{16}$ in. minimum per side must be allowed.

Tool Design.—Avoid all sharp angles and abrupt alterations of section, as these localise quenching stresses and may cause cracks or fractures. Avoid excoriation or indentation of the tool during forging, stamping, or grinding. Avoid lines of weakness, e.g. a number of holes in a straight line. When cutting channels or grooves in steel, round off the sharp corners if possible.

Heavy machining cuts may set up stresses and eventually lead to hardening cracks. Stress-relieve (normalise) to prevent this. (Heat to 480–595° C. and cool in the air.) High-speed steels should be fully annealed.

Specific Gravity of Steel.—Approximately 7·85, while that of grey cast iron averages 7·22, and that of white iron 7·65. High-speed steels are much heavier than ordinary tool steels, and specific gravity varies from 8·45 to 8·75 according to composition. In calculating high-speed steel weights, add 10 per cent. to the weights of carbon steels for qualities up to 18 per cent. tungsten or the equivalent. For high-cobalt, high-speed steels add 12½ per cent.

METHODS OF TESTING HARDNESS

The Brinell Test.—It is customary to determine the hardness of a metal by measuring the indentation produced in it by a hardened object forced into it under a calculated pressure. The first and probably best-known machine for carrying out this test is the Brinell. In this, a hardened-steel or tungsten-carbide ball is forced into the metallic surface under a specific load, and when this load is removed, a permanent circular indentation is left in the metal, the area of which is measured. Hardness is calculated by the formula $B = \frac{L}{A}$, where B is the Brinell number, and A is the spherical area of the indentation in square millimetres, L being the load in kilograms.

Spherical area of the indentation involves certain calculations for its determination. The area of the ball used is πD^2, so that the formula for finding the indentation area is $\frac{\pi D^2 h}{D} = \pi D h$, where h is the height or depth of indentation and D the ball diameter, but as it is simpler to measure the diameter d of the impression in place of the depth, the expression more usually employed is

$$B = \frac{L}{\pi \frac{D}{2}(D - \sqrt{D^2 - d^2})}.$$

To carry out this test, the specimen must be placed on a movable table, which is elevated by a hand wheel until the previously prepared surface is brought into contact with a hardened ball. A valve is closed and oil pressure applied by hand pump to the ball and a gauge graduated in kilogrammes. Pressure is constant, but the load may be varied if desired. If it is desired to vary the pressure, this may be done in the standard machine in amounts of 500 kg. between 500 and 3000 kg.

The load should be applied for a minimum period of 30 seconds for soft metals. Pressure should then be removed and the test-piece lowered. The impression diameter is measured by low-power microscope with graduated eyepiece. The ball diameter is standardised at 10 mm. in the Brinell machine, but modifications of the machine employ balls of 1-, 2-, or 5-mm. diam. with loads variable between 10 and 50 kg.

The following precautions should be observed in making the Brinell test. Test-piece thickness must not be less than 7 × D for hard materials, or than 15 × D for soft materials, D here being the depth of impression. The load must never be so heavy as to show a convexity on the back of the piece tested. If the indentation is not fully circular, maximum and minimum diameters should be measured and the mean value used in determining hardness. Test-piece width must not fall below two and half times impression width. Test-piece prepared surface must be level and smooth, and if the test is to be carried out on one of the "Baby" machines, it will need to be finished off with emery paper.

The Brinell hardness of a metal is to some extent an indication of its tensile strength, which may be ascertained if the Brinell number is multiplied by a constant, whose value is governed by the character of the alloy. In practice, tables are used for this purpose, see p. 227.

The Rockwell Test.—The Rockwell test differs from the Brinell test in that the method of producing an indentation is the use of a diamond cone, though a $\frac{1}{16}$-in.-diam. hardened steel ball may be used if desired. For this reason the machine has a dial graduated in two scales, shown as B and C, representing the two types of indentor. The diamond cone has a 120° angle. The first stage in the test is the application of a minor load of 10 kg., designed to "set" the cone or ball. This is shown on an auxiliary micrometer dial at a point marked "set." The main dial's pointer is then set at zero, and the major load is applied. This is 100 kg. for the steel ball and 150 kg. for the diamond cone. Pressure is applied by pressing a button, and is released by a side lever, after which the hardness number is read off the dial of the machine. The graduations run from zero to one hundred, or, for the diamond scale, 20–100, corresponding with one full revolution of the pointer and an actual penetrator movement of only 0·2 mm. Time taken is 10 seconds. So long as the test-piece surface is clean, no special

surface preparation is needed. Hardness scales are, however, more open and less discriminating than the Brinell. The specimen's hardness is primarily indicated by the difference in depth between two superimposed impressions, so that the risk of error as a result of measuring merely superficial hardness is largely obviated.

Avery Test.—The Avery testing machine is closely akin to the Rockwell in design and principle, but is a newer type and is said to have a better measuring device.

Relation between Brinell and Rockwell Numbers.—While there is a relation between the Brinell and Rockwell numbers and similarly between Vickers

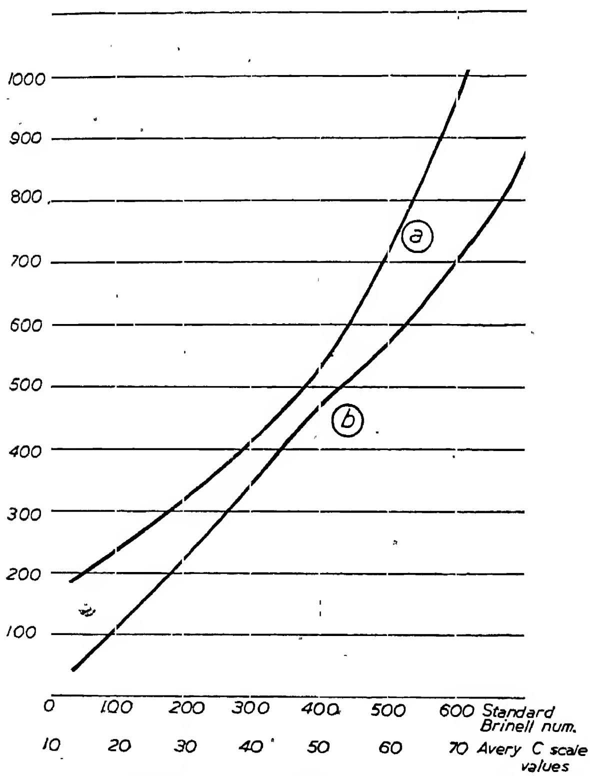


Fig. 3.—Graph showing (*a*) relation between Vickers and Avery C scale values, and (*b*) Vickers diamond and Brinell ball hardness numerals.

diamond and Avery or Rockwell C scale values, it is a purely approximate one. Some formulæ have been put forward to express these relations, based on data obtained from experiments, but it should be noted that these apply with any precision only to metals much alike in composition and in an identical specified condition. Not only will any change in composition, heat treatment, or amount of plastic cold deformation cause changes in the empirical relation, but similar

changes will occur if the loading ratios chosen in the Brinell test are varied. Fig. 3 shows the relations between : (*a*) Vickers diamond and Avery C scale values, and (*b*) Vickers diamond and Brinell ball (10 mm., 3000 kg.) hardness numerals.

Vickers Diamond and Firth Hardometer Tests.—The Brinell test has defects. Sometimes, for reasons that need not be detailed, the hardness shown is less than that of the actual metal under test. Sometimes, again, the metal tested may be so hard as to deform the ball, so that wrong hardness figures are obtained. This is why the conical or pyramid-shaped diamond is used in the more modern hardness testers. The Vickers machine uses a diamond pyramid (or balls, if required). The hardness number is found from the formula: $H = \frac{2L \sin 68^\circ}{d^2}$, where H is the Vickers hardness number, L the load, and d the diagonal of the base of the pyramid, this being more readily measured than its side. Measurement of the diagonal is by means of a micrometer ocular. As he looks through the eyepiece, the operator makes the left-hand extremity of the diagonal coincide with a fixed knife-edge by means of two focusing screws. The impression's diagonal is next measured by revolving the knurled head, which operates a digit counter mounted on the side of the ocular and a movable knife-edge inside the eyepiece. When properly focused and regulated, the impression image has the appearance shown in Fig. 4.

The ocular reading multiplied by 0·002 gives the diagonal length in fractions of an inch. In practice, conversion tables convert the ocular readings into corresponding hardness values. The load is variable from 1 to 50 kg.; test duration is automatically controlled, and load itself is governed by hardness and structure of the metal being tested, a small load being used for soft metals. The test-piece should have its surface prepared by polishing with 00 emery paper.

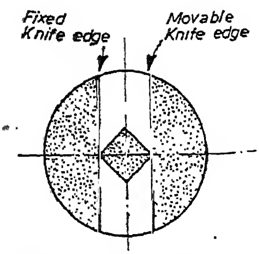


Fig. 4.—Impression image, when Vickers hardness testing machine is correctly focused and regulated.

The Firth Hardometer resembles this machine, but is less complex in construction, while the 10-, 30-, or 120-kg. load is applied by compressing calibrated spiral springs, thus eliminating inertia effects.

The Shore Scleroscope and the Herbert Pendulum Tester.—In the Shore scleroscope, a diamond-pointed hammer is permitted to fall freely from a previously fixed height on to the surface of a test-piece. The height to which the hammer rebounds is measured and regarded as an indication of hardness. In the Herbert pendulum test, a weight system resting on either a steel ball (1-mm. diam.) or on a diamond in the form of a ball, comprises a compound pendulum. This is placed on the testpiece surface, on which the ball makes an impression, and is then oscillated through a small, predetermined arc. The period occupied by the swing is afterwards regarded as an index of the metal's hardness.

Keep's Test.—This is a method of measuring hardness based on the depth to which a twist drill penetrates when running under constant conditions of speed and pressure. An autographic record is taken of the progress of the drill.

Moh's Scale of Hardness.—This is a scale invented as a means of determining the comparative hardness of mineral substances. Its basis is the knowledge that one object will abrade or scratch the surface of another of identical or less hardness, but not that of one that is harder. This property is known as scratch hardness. Moh's scale is as follows : (1) talc, (2) rock-salt or gypsum, (3) calcite or calc spar, (4) fluorspar, (5) apatite, (6) feldspar or orthoclase, (7) quartz, (8) topaz, (9) sapphire, (10) corundum, (11) diamond.

Turner's Sclerometer.—This is a method of determining the hardness of a metal based upon the weight required to produce a visible scratch when a diamond point is dragged across the surface of the testpiece. The instrument employed is termed the sclerometer. It is not much used in Great Britain, but has some application in the United States.

Monotron Test.—This machine records on a dial the load necessary to make a definite penetration of a metal. There are two dials, one measuring pressure, the other depth of penetration in both soft and hard metals. Surfaces may be either prepared or unprepared. Penetration is first made to a pre-established standard depth with the help of a compensated depth micrometer indicator. Hardness numeral is next read from the pressure dial in kilogrammes per unit area while the testpiece is still under load. Load is removed, and the depth indicator reverses in the zero direction just as far as the elastic recovery of the testpiece allows. The number of divisions between the indicator and zero point then show the extent of permanent deformation. The indentor is a diamond ball $\frac{3}{4}$ mm. diam. It penetrates to a depth of $\frac{9}{5,000}$ in. With this is employed Scale M-1 reading directly in Brinell numbers. A $\frac{3}{4}$-mm. diamond point is also used, and the test is then known as the 100-kg. Monotron or Monotron Diamond. Larger balls are employed for dead-soft metals.

Hot-hardness Tests.—These are still the subject of research and experiment. It will be appreciated that it is often necessary or valuable to know the approximate or precise hardness of a metal at elevated temperatures. Most of the ordinary hardness-testing methods have been applied for this purpose, but no standard procedure has yet been worked out. In general, a tungsten-carbide indentor gives better results than a steel ball, being more able to withstand the high temperatures. It can be used up to 800° C. The diamond indentor can be used up to 800–980° C. The steel ball, on the other hand, should not be used for temperatures above 200° C., as it then begins to soften. In one hot-hardness test, the material being tested is employed as the indentor, the method being known as mutual indentation, and applied to high-speed steels whose hardness at high temperatures it is desired to establish. Most experts are of the opinion that the best method, however, is one in which both indentor and testpiece are heated to the specific temperature, and the test made by either the static or the impact method. Heating of the test-pieces is carried out for the higher temperatures in an electric furnace, or, for the lower temperatures, in water, glycerine, cylinder oil, or perhaps a fused salt bath.

IRON AND STEEL MANUFACTURE

Iron Ore.—Most British steel is made from iron ore produced in Cumberland, the Carnforth district of Lancashire, Northamptonshire, etc. Some iron ore is in normal times imported from the Bilbao and Santander districts in Spain, and there is reason to believe that a little is now being obtained from Algeria and Morocco. Most of these ores are hematite ores. Pig iron is also made from a black, magnetic ore known as magnetite, the hematite being non-magnetic. Hematite iron ore is separated from the vein stuff by water, the method being based on the difference in specific gravity between the two materials. Sometimes, with calcareous ores containing carbonaceous material, the iron existing as a carbonate, roasting or calcination is carried out to concentrate them. Iron ore most be low in sulphur and phosphorus. High sulphur is highly detrimental to most steels. High phosphorus may be partly remedied in the steel-making process. The ore must also be rich in iron.

Pig Iron.—Pig iron is made in the blast furnace. A flux is essential to eliminate the impurities by forming them into a slag that may be skimmed off. The blast furnace is charged with the calcined and weathered iron ore, runs continuously for perhaps two or three years, and is only damped down when its lining needs replacement. With the ore, charcoal and limestone (the flux) are charged. Some British blast furnaces are 100 ft. high and will handle 500 tons of ore a day.

Air is blown into the furnace through tuyères at the base. The air is preheated in stoves, and dried by passing it over silica-gel on trays, which absorbs the moisture. The upper extremity of the furnace casing is sealed by a conical bell, which fits into the lower portion of a hopper, so that the charge is allowed to go in, but no gas can come out. The air blast acts on the fuel of the charge, and generates intense heat. The heated gases given off are rich in carbon monoxide. They descend through the charge and reduce the iron oxide to the metallic state. This reduced iron then liquefies and falls to the bottom of the furnace, taking up

carbon and silicon en route. The vein stuff of the ore combines with the flux, which has been converted into lime by the hot gases, and forms a fusible slag, which, floating on top of the metallic iron, can be drawn off before the iron itself is withdrawn. The entire process may be represented by equations: $Fe_3O_4 + 4CO = 3Fe + 4CO_2$ (production of metallic iron and carbon dioxide; $CO_2 + C = 2CO$ (carbon dioxide and fuel produce carbon monoxide); and $SiO_2 + 2C = Si + 2CO$ (silica in the ore reduced to silicon and passing into molten iron).

Various other impurities (alumina, coke ash) combine with the lime to form part of the slag. The waste gases help to heat the ore calciners and the air blast. The molten iron runs out of a taphole in the bottom of the furnace, below the slag hole, and passes into a main sand channel (the sow) from which minor side channels branch off (the pigs). The metal is broken up as soon as solid but still hot, and loaded into trucks.

If the iron is to be used immediately, while still liquid it is teemed straight into large ladles. It may also be cast into pigs by a special casting machine, the moulds being of iron instead of sand.

The Brassert Acid Burdening Process.—A British pig-iron producing process. In this, the slag is siliceous and the iron relatively high in sulphur. To lessen this sulphur content, the molten iron is teemed into ladles containing soda-ash, which is decomposed by the heat, and the sodium oxide freed thereby combines with sulphur to form sodium sulphide. This and the iron oxide form a floating slag which may be readily skimmed off. Usually the desulphurised iron is teemed into a mixer, the required quantity being taken as necessary. This method also lessens the silicon content of the metal.

The Puddling Processes.—Pig iron contains 5–6 per cent. of impurities, which percentage must be reduced before the iron can be made into high-quality steel. One method adopted is the Walloon puddling process for producing wrought iron. A furnace with a rectangular hearth of cast-iron plates water cooled has a single open pipe for the admission of an air blast. Charcoal heats the furnace, and the pig iron is introduced at the rear end. On the floor external to the furnace are a number of wooden rollers on which a long D-formed pig-iron "cake" is laid. These cakes weigh about a ton and have a special cast shape. They are moved into the furnace with the aid of levers until their extremities project above the hot part of the furnace, where the air blast encounters the charcoal. The pig ends then liquefy, drop by drop, over the fire, and are progressively moved forward until enough iron has been melted to form a large 70–90-lb. mass in the furnace bottom. This mass is continually manipulated in the region of the blast by an iron bar, and when ready is grasped with tongs, broken up, and lifted above the pipe in order to raise it to a welding temperature. It is then taken out of the furnace and formed into a bloom under a power hammer. The temperature is never high, so that the iron is always in a pasty condition, never completely melted.

In the Swedish Lancashire process, higher temperatures are used, the air blast being preheated and there being two or more pipes. In the English puddling process, the impurities combine with oxygen in the form of iron oxides, and a reverberatory furnace is used, there being no air blast.

Blister Steel.—This is formed by the cementation process from wrought bar iron. Firestone or earthenware chests contain up to 25 tons of wrought-iron bars, $2\frac{1}{2}$–3 in. in width, $\frac{5}{8}$–$\frac{3}{4}$ in. thick, by approximately 12 ft. in length. There are two chests to a furnace. The bars are packed in layers separated from each other by layers of charcoal. Air is carefully excluded. The chests are heated, maximum temperature being attained only at the end of 3–4 days. Temperature is maintained for from 7 to 11 days according to the carbon percentage desired, the maximum time corresponding to the maximum carbon content. The steel then cools for another 4–6 days, the chests are broken open, and the result is a highly brittle steel whose surface is covered with blisters caused by the reaction between the included slag and the carbon.

Shear Steel.—A high quality of carbon tool steel made by breaking up blister-steel bars into pieces 18–20 in. long, heating these to 900° C. and hammering them under a power hammer to flatten out the blisters and toughen the steel. Five to seven "plated bars," as they are termed, are packed into a handled steel clip, wedged tight, heated to 1200–1300° C., and coated with sand or fluorspar, then

hammered at 1200° C. and welded together to form a faggot or bloom. This is "single-shear" steel. To make double-shear steel, the bloom is nicked centrally, and bent back on itself, then rehammered down to its original dimensions.

The Bessemer Process.—A process of making steel in which liquid pig iron, melted previously in a cupola furnace, has a blast of air blown through it mechanically in a pear-shaped vessel. The oxygen in the air blast combines with a number of the impurities contained in the iron, and as a result of the various chemical reactions arising, intense heat is generated, helping to keep the iron liquid. The oxides thereby produced chemically combine to make up a fluid slag rising to the top of the vessel. Some of the impurities are blown out of the vessel's mouth as sparks.

The vessel itself is termed the converter, and is composed of a mild-steel shell with a lining of refractory material, either *acid* or *basic*. Which type of lining is adopted is dependent on the chemical composition of the pig iron used. In the acid process, silicon, manganese, and carbon are the impurities removed. In the basic process, phosphorus and a proportion of the sulphur are removed. The molten iron is first melted in the cupola, together with a proportion of steel scrap, coke, limestone, and fluorspar. The limestone fluxes the metal to eliminate as much sulphur as possible.

In big Bessemer installations, a mixer is often used midway between cupola and converter, and comprises a large receiver or furnace into which the iron from the cupola is periodically run, and from which the converter in turn receives its charge. In this mixer some of the manganese and silicon is oxidised, while in the basic process a considerable amount of sulphur is also removed.

The converter itself has a flat bottom with a series of holes in it for the admission of the air blast, the holes being formed in specially designed refractory bricks let into the furnace bottom. Air blast is provided by a blowing engine located in a nearby blowing house.

The lining of the acid process is rammed ganister. In the basic process, the lining is of rammed dolomite or magnesian limestone.

The Open-hearth Process.—A method of manufacturing steel comprising the oxidation and elimination of impurities contained in molten iron lying in the hearth of a special furnace. The actual melting chamber is a comparatively shallow furnace floor open or exposed to the action of the flame. Thus, the relation of depth of molten bath to surface area is not large when contrasted with that of the crucible or Bessemer processes.

The lining of the furnace may be either acid or basic. The fuel is gas, generated from coal in gas producers, and the air for combustion is independently heated in special regenerative chambers. The hot waste gases pass through recuperators, thereby heating the brickwork on their way to the chimney. At regular intervals the direction of the heating gas, the air, and the hot waste gases is reversed. In this way the incoming gas and air are always kept very hot before they mingle and burn in the furnace hearth. Otherwise the process would not be operative.

The hearth of the furnace is roofed with a refractory brick arch. In each end of the melting chamber are ports for the passage of the air and gases, and the regenerative chambers are connected by vertical flues with the ports. Slag pockets below the flues collect dust and slag for removal. The ports are all slanting so as to keep the hot air and gases away from the roof, and the air port is above the gas port. In the acid open-hearth process, the pig iron must be low in sulphur and phosphorus, and have a reasonable silicon content. In making up the charge, a proportion of steel scrap larger than the proportion of pig iron is used. The higher the carbon content needed in the steel, the higher the pig-iron proportion. An average of about 1 per cent. of silicon is aimed at. The pig iron is usually charged first, with the scrap next, to prevent damage of the lining. The carbon content of the bath is usually much higher than is desired in the final steel, so that hæmatite ore is added to oxidise some of the carbon, as well as silicon and manganese.

If the carbon is too low, more pig iron is added to produce more heat and raise the carbon content. At the end of the process, a small quantity of ferro-silicon and/or a manganese-iron alloy may be inserted to stop further oxidation and carbon elimination and to help to deoxidise the bath. Open-hearth furnaces range from 10 to 300 tons. Those of capacity over 150 tons are generally of tilting

type. Manganese, and sometimes silicon, is added to the steel in the ladle to remove harmful oxides. Nickel and chromium for alloying purposes are added in the furnace; manganese, vanadium, titanium, etc., in the ladle. Aluminium is usually added to the ingot mould.

The Crucible Process.—In the Huntsman crucible process, fine tool steels are produced by breaking up blister-steel bars into small pieces and melting them in a covered clay crucible. According to the carbon percentage required in the final steel, high-quality steel scrap, Swedish or equivalent wrought iron, white pig iron, and charcoal are carefully weighed and added to the charge. The clay crucible is placed in a coke- or gas-fired furnace of regenerative type (oil is also used in some plants). Special alloys, such as tungsten, chromium, and nickel, are added with the charge. Manganese, vanadium, etc., are dropped in as small packets while the steel is being melted. The ingot moulds are coated with soot to stop the steel from adhering to their sides, this soot being formed by burning creosote under them.

The crucible and its charge are heated up for about 4 hours, until the steel is completely melted and ready for teeming. The pots are then extracted with tongs by a single operator. The refractory lid of the crucible is taken off, and the slag on the surface of the metal skimmed off. The moulds are slightly tilted to enable the steel to reach the bottom of the mould without washing down the sides.

When teemed, the steel is allowed to solidify and decline to a red heat. The wedges and rings binding the mould are then removed, and the steel ingot withdrawn.

The crucibles are made from special fireclay mixed with approximately 5 per cent. of good ground coke dust. They are roughly moulded by hand and given their final form by a mechanical press. Drying for 10–14 days follows, after which the pots are heated on grates to a good red to anneal them and transferred straight to the melting holes. Slow drying and annealing are essential. The pots will last for only two or three charges before being discarded, and after each melt must be put straight back into the furnace while still red hot, to prevent cracks.

Plumbago crucibles are sometimes employed, especially for making small castings, and last longer than the clay pots, while they can be allowed to cool to normal temperature and reused without danger of cracks. They tend, however, to introduce undesired carbon into the steel until they have been used for about seven heats, though this can be allowed for.

The High-frequency Electric Induction Crucible Process.—First introduced for tool-steel manufacture by Edgar Allen & Co., Ltd., in 1927, this process has revolutionised the manufacture of fine steels, and is rapidly ousting the old Huntsman crucible process from its former position. In the manufacture of fine tool and other steels, it is essential that impurities such as sulphur, phosphorus, etc., should be prevented from contaminating the steel. This is not easy, and was never fully attained until this process was invented.

Like the crucible process, this process involves the melting of the metal in a refractory crucible, but here the pot is enclosed in an inch or so of loosely packed special heat-insulating sand held in place by an external cylinder of mica sheet or asbestos. Zirconia sand is often used for this purpose, which is to protect the water-cooled copper coil surrounding the crucible should the pot itself crack and allow molten metal to exude through the gap. The entire assembly is enclosed within a cylindrical tube or coil of copper, through which cold water is continuously passed, to prevent the heat from affecting the copper of the coil.

Furnaces up to 10 tons in capacity are now used for making high-quality alloy steels. In the larger furnaces, the lining is somewhat differently formed. The coil is protected by a thin cylinder of asbestos or mica, and inside this cylinder is placed a hollow steel plug, the refractory material for the lining being carefully rammed between coil and plug. Thus, the furnace may be lined with either acid or basic material, as desired. The current is then switched on and, passing through the coil, slowly raises the plug's temperature until it melts, by which time the surface of the lining has already fused into an impermeable refractory mass. Afterwards, when metallic charges are introduced, the current passed through the copper coil generates eddy currents in the charge, which melts.

The walls of the crucible or lining act only as container, and no heat is transmitted from the exterior of the crucible to the charge. The eddy currents induced, generating heat in the charge, vary as the square of the frequency. Consequently, a high frequency is essential, and this involved the development of specially designed motor generators to provide the current at suitable voltage and frequency. The first such generator ran at 3000 r.p.m. with 1200 volts' terminal voltage.

The assembled furnace and coil are contained in a wooden case, and pouring is done by tilting the whole furnace bodily in an ingenious way that maintains the pouring lip constantly vertical, thus ensuring quick and safe manipulation. As no heat is conveyed to the charge from outside, there is no contamination of the metal.

The charge quickly rises in temperature, and as soon as it is melted, the eddy currents impart a circulatory motion to it in a vertical direction, i.e. the metal rises up the middle and descends down the sides. When the steel, e.g. high-speed steel, contains heavy alloying elements, such as cobalt, tungsten, etc., this motion ensures complete distribution throughout the mass of the heavy metals, which might otherwise fall to the bottom of the crucible and produce a steel lacking in homogeneity.

The process produces a remarkably pure and sulphur-free steel if the charge itself is low in sulphur ; steels to special analysis may be made quickly ; higher uniformity of steel is obtained ; close control of temperature is possible ; intermittent operation with little loss of efficiency is feasible. Moreover, less space is needed for production of an equivalent amount of steel as compared with the crucible process ; the furnace capacity is more convenient than the 60–80 lb. per crucible of the older process ; the crucible can be easily emptied at each heat ; many small quantities may be teemed before the temperature falls too low ; reheating is achieved quickly and easily by the movement of a switch ; 400 lb. of steel may be melted in 55 minutes or even more quickly in the larger furnaces, as against 4 hours required by the Huntsman process, while conditions for the furnace operators are incomparably cleaner and less arduous.

The Arc-furnace Process.—This is an electric steel-making process in which the necessary heat is obtained by passing a powerful electric current through two or more electrodes or between the electrodes and the bath of metal, thus forming an arc or arcs whose intense heat melts the charge. The first type are termed *indirect* and the second *direct* furnaces.

The furnace is lined with dolomite or magnesite, or a mixture of both, bonded by the admixture of boiling anhydrous tar, and crushed basic slag. Sulphur and phosphorus contents between 0·01 and 0·015 per cent. are aimed at. The furnace is charged with steel scrap made by one or other of the usual processes. This scrap is melted under oxidising conditions in the presence of a highly basic slag, thus eliminating phosphorus, silicon, and carbon. The phosphorus-containing slag is removed, and the bath is then recarburised to the desired extent. Finally, a slag and atmosphere of reducing type are formed inside the furnace, so as to eliminate oxides from both slag and metal, and to desulphurise the steel.

The first stage is designed to eliminate phosphorus and silicon. The second stage is accomplished by the mechanical tilting of the furnace to draw off the slag, and the addition of anthracite to yield the required quantity of carbon. The final stage comprises adding such reducers as ferro-silicon and carbon, in the form of finely crushed coal, coke, or possibly old electrodes, to the slag.

The furnace having been charged, the current is switched on and the electrodes are lowered until arcing occurs between their extremities and the bath. A portion of the charge is melted by the fierce heat generated, and a pool of liquid metal is created between the electrodes. Lime, limestone, iron ore, fluorspar, or/and sand are then added to form the requisite type of slag. Pure white sand is often added to the slag just before the furnace is tapped in order to thin it. Additional thinning may be necessary, in which case a minor amount of ferro-titanium is added to the ladle.

Steel may also be produced by the electric-arc furnace without oxidation. Pure steel scrap is essential, and slag-forming ingredients must be added earlier. Lime, fluorspar, ferro-silicon, and crushed coal or coke dust are added as reducers as soon as the bath is fully molten. It is not necessary to remove the slag.

There are alternative methods that may be used for producing high-chromium steels and irons in the electric-arc furnace.

Steel Ingots.—These may be either top or bottom poured. Top pouring is more usually applied to ingots of comparatively small dimensions. In bottom pouring, several moulds are grouped radially and connected by fireclay channels to a central fireclay pipe or trumpet. The number of moulds may be 4, 6, or 8. All are filled simultaneously. The object is to avoid splashing, causing bad-surfaced ingots; to give a smoother skin to the ingot; and to give a more uniform casting temperature of the entire charge. Careful control of casting temperature is necessary to prevent erosion of the fireclay channels, causing non-metallic inclusions in the steel.

Top-pouring splash has been minimised by use of the tundish, a refractory-lined box with nozzles in the bottom placed on top of the mould or the feeder heads, and serving as a secondary ladle. A splash can is another contrivance for the same purpose. This is a thin sheet-steel, open-topped cube placed on the mould bottom in advance of teeming. The splashes then collect on the splash-can walls instead of on the ingot sides, and eventually the can itself is dissolved by the molten metal.

Defects in Steel Ingots.—Slag inclusions are non-metallic particles entering the mould with the molten metal and becoming caught and held. Forward-tilting furnaces are more liable than the stationary open-hearth furnace to trap slag particles in this way. Slag is not the sole cause of these inclusions. The killing of molten steel forms oxides of manganese and silicon, and manganese-silicate inclusions, alumina inclusions, etc., may occur. To minimise oxide inclusions, two or more deoxidants are usually employed combined in the one alloy, e.g. silico-manganese and silicon-manganese-aluminium alloys. Slag and other inclusions may also be reduced in number by allowing the steel to stand in the ladle for a period in advance of teeming.

Pipe is the contraction cavity formed when correctly deoxidised steel completely solidifies in the moulds. These contraction cavities are prevented by the use of "dozzles" on small ingots and feeder heads on larger ones, serving as receptacles for surplus molten metal, which slips down to fill up the cavity as it forms.

Ingot cracks arise during the cooling of an ingot, and are found more often when the casting temperature is too high. Cracks of transverse character may arise as a result of improperly fitting feeder heads, and are then usually restricted to the top portion of the ingot. Longitudinal cracks arise from uneven cooling. Both types of cracks may also be caused by bad moulds.

Cracks may also be caused by allowing ingots to grow quite cold before reheating; pouring the steel too quickly into the mould; and too much splash.

Laps or folds are largely caused by too slow a rate of pouring.

Segregation is a concentration of impurities in certain zones of the ingot, and is mainly due to casting at too high a temperature, the particles being trapped by the branching arms of the dendritic crystal formations arising as steel cools from the molten state.

Blowholes are gas cavities caused by the liberation and failure to escape of gas during steel's solidification. They are usually caused by imperfect deoxidation of the steel.

Rokes and seams are largely due to ingots whose surface is defective by reason of one or other of the defects earlier mentioned.

Steel Castings.—Steel castings may be made in the Bessemer converter, Siemens open hearth, high-frequency electric crucible, electric-arc and Huntsman crucible processes. The larger castings are, however, mostly made by either the Siemens or the Bessemer (or Tropenas) process. The Stock converter, in which melting and blowing are carried out in the same vessel, is also used in this country. Of late years, oil-fired crucible furnaces have also proved suitable for the manufacture of small steel castings.

A wooden pattern is first required, which is imprinted in a sand mould, the mould being made of different types of carefully chosen sands, bonded and dried. Cores, to form hollowed-out portions in castings, are often made by an oil-sand process, in which a special binder is employed for the sand and a vegetable oil mixed in. Sea sand is often employed for making cores. The mould must be

given adequate runners and feeding heads, representing approximately one-third of the total amount of steel used in making the casting. Casting temperature is specially important. Highly intricate castings may benefit by being inserted while still hot in a preheated annealing furnace, to avoid uneven contraction in cooling.

Heat treatment of steel castings is carried out after they have been fettled to remove all adherent sand, fins, rough fash, etc. Feeder heads are removed by the oxy-acetylene torch, the circular or band saw, or by machining in a lathe, planer, slotter, or shaper. Rough machining of the castings may be required. Final grinding to smooth up surfaces and finish off the parts follows. Electric welding may be necessary to close up superficial defects. Warped castings may need rectification by straightening in the press, or by hand hammering after a preliminary heating. To clean the castings, a tumbling process may be adopted, but in most modern foundries the shot-blast method of cleaning is adopted, in one of the highly efficient machines designed for the purpose, or in special shot-blast chambers where jets of chilled iron shot are directed by operators on to the areas to be cleaned.

Heat treatment comprises annealing, normalising, or quenching followed by tempering. Annealing is done by heating the castings to not more than 50° C. above the Ac_3 point in the iron-carbon diagram (p. 195), and soaking for several hours, according to mass, after which cooling in the furnace follows. Normalising follows the same procedure, except that the castings are cooled in the air, which gives a rather finer structure, with slightly superior mechanical properties. Quenching and tempering are not recommended unless the casting is of practically one and the same thickness throughout its length, in which case, after having been annealed, it is heated to approximately 50° C. above the Ac_3 point and quenched in water, oil, or air, then reheated to a temperature below the Ac_1 point and air cooled.

Types of steel for castings made in this country are given in Table on p. 210.

Manganese-steel Castings.—Many parts of crushing and grinding machinery, cement plant, dredging and mining machinery, as well as points, crossings, tongues, junctions, and switches for railways and tramways, are made in the form of manganese-steel castings. The steel concerned is an austenitic steel containing 12–14 per cent. manganese. It is quenched at 950–1000° C., when it may be bent in the cold condition without fracture. Though soft in itself (Brinell No. 200), it work-hardens immediately it is cut, abraded, etc., and in consequence becomes ideal for parts and purposes in which high wear and abrasion resistance, combined with toughness and strength, are required. The metal is highly ductile, and is not, therefore, the best steel for castings that have to withstand repeated impact, owing to its flow or spread. Depth hardening partly remedies this, while an alternative remedy is to modify the standard analysis of the steel to produce a casting equally high in tensile strength, but with a higher elastic limit and more effective resistance to flow under impact.

Semi-steel Castings.—Semi-steel is not strictly a steel at all, but a cast iron in making which a small proportion of steel scrap has been added to the pig iron. The actual proportion is approximately one-third to one-fifth of the total weight of the charge. The metal is melted in a cupola furnace, and the result is a cast iron with a lower carbon percentage (2·5–3·2 per cent.), which is rather tougher than ordinary cast iron, and is extensively used in making heavy castings, such as hydraulic rams and cylinders, diesel-engine cylinders, etc. A high-grade hæmatite is normally the basis material, and the molten material is cast as hot as possible to make sure that the resulting products are sound and free from non-metallic and other inclusions.

Malleable-iron Castings.—While ordinary cast iron may be used for many cast parts, it is not strong and tough enough for many purposes, and for this reason malleable-iron castings are made. The combined carbon of white cast iron is converted by modification of the composition and by annealing into an amorphous, uncombined condition. The graphite into which the carbon is thus converted is embedded in the iron matrix, and the result is a soft and partly malleable material much stronger and far more ductile than ordinary cast iron. Irons containing up to 0·25 per cent. phosphorus are employed, having a much smaller carbon percentage than the normal foundry iron. A high silicon content

is necessary. The white iron castings are heated to approximately above 750° C. but below 1100° C. Such a casting would give a composition of 1·98 per cent. total carbon, a trace of combined carbon, 1·2 per cent. silicon, 0·057 per cent. sulphur, and 0·172 per cent. phosphorus, with maximum stress 25·72 tons per sq. in., 14 per cent. elongation, and a Brinell numeral of 143–148. This practice originated in the United States. In Britain and to some extent in Europe the white-iron castings are often packed in hematite iron ore and heated to between 800 and 900° C., for a considerable period.

Meehanite Iron.—This is a special cast iron costing rather more (approximately 10–20 per cent.) than normal high-quality cast irons. Its typical composition is 2·4–2·7 per cent. total carbon, 1·0–1·5 per cent. silicon, 0·65–1·0 per cent. manganese, 0·05–1·14 per cent. sulphur, 0·1–0·2 per cent. phosphorus. The method of manufacture is by treatment of the cupola metal with an electric-furnace compound of calcium (calcium silicide), which causes graphitisation. The material gives an average tensile strength of 20–30 tons per sq. in. It can be chilled and heat treated, chilling being to any required depth with a potential Brinell hardness ranging from 300 to 500.

Alloy Cast Irons.—The addition of alloying elements to cast iron is relatively recent. The principal alloying elements used to-day in Great Britain are nickel, chromium, copper, and manganese, but in the United States vanadium and molybdenum are also used. The elements may be added singly, or an iron may have two or more alloying elements in its composition, according to the purpose for which it is required.

Nickel is added to give the iron higher mechanical strength and greater toughness. A typical iron used for high-quality automobile engine castings contains 1·14 per cent. nickel, but as much as 2·3 per cent. has been employed. A good nickel iron has an average tensile strength of 20·5 tons per sq. in., with a Brinell numeral of 215. Machinability is also improved by nickel; chill is minimised.

Chromium produces a harder cast iron, accentuates the chill, and has high wearing properties. Furthermore, expansion and contraction resulting from repeated heatings are minimised, and grain is refined. On the other hand, machining is more difficult. About 0·4–0·5 per cent. is added.

Copper gives the iron a greater power of withstanding corrosion. Up to 3 per cent. may be introduced into the metal.

Manganese to the extent of 5–10 per cent. produces a non-magnetic iron ("Nomag") when associated with 10–15 per cent. nickel. The iron has also low permeability and high electrical resistance, combined with good machining properties. It is widely used for cast parts of electrical plant such as motor end rigs, switch covers, resistance grids, etc.

One of the most commonly used alloy cast irons, both here and in the United States, is nickel-chromium cast iron, which is being used for such parts as cylinder liners, crusher jaws and crusher parts, cast-iron dies, etc. It has been found that such an iron possesses the maximum combination of strength, wear resistance, and machinability, as well as a fair degree of toughness. The nickel percentage ranges, according to purpose, from 1·7 to 4·02 per cent., and the chromium from 0·4 to 1·25 per cent. A typical high-quality cylinder iron of this type for heavy duty has a Brinell number of 289. Dies of nickel-chromium cast iron (1·7 per cent. Ni, 1·24 per cent. Si, 3·4 per cent. C, 0·4 per cent. Cr) have considerably outlasted ordinary cast-iron dies.

Copper is sometimes added to nickel-chromium cast iron containing 12 per cent. nickel and 7–8 per cent. chromium to give a highly corrosion-resistant cast iron, much employed in the manufacture of pumps and chemical equipment.

Safety valves have been and are still manufactured from an alloy cast iron containing high percentages of chromium and manganese, which is extremely hard. In the United States a nickel-chromium-molybdenum iron and a vanadium cast iron are also used. Molybdenum produces a higher tensile strength and greater hardness. It is usually added in percentages from 0·25 to 1·25 per cent. In combination with nickel and chromium, it yields an iron of high wear resistance, good density, high Brinell hardness, and high strength.

Vanadium is added in percentages ranging from 0·1 to 0·5 per cent. It produces an iron having great hardness, toughness, and wear resistance of chill. Tensile

strength and transverse strength are also improved. It may be used alone or in combination with nickel, chromium, and molybdenum.

Titanium may also be used as an alloying element to refine the structure and give a higher-strength iron. In combination with chromium, it gives good strength and machinability. It has also been used in combination with vanadium and molybdenum.

Steels for Cast Crankshafts.—Various steels have been and are being used for making crankshafts by a casting process. Typical compositions are (*a*) 0·5–1·5 per cent. chromium, 0·5 per cent. molybdenum; (*b*) 1·5–2·0 per cent. copper, 1·0 per cent. silicon, 1·5 per cent. carbon. The first of these may be annealed at 1010° C. or normalised at 955° C. The second should be heated to 900° C., and air cooled to 790° C., or furnace cooled to 725° C. and slowly air cooled. The first steel will give a tensile strength of 45 tons per sq. in. with a yield point of 33 tons per sq. in., an elongation of 18·8 per cent. in 2 in., and a reduction of area of 46·7 per cent. The second steel gives a tensile strength of 35 tons per sq. in., an elastic limit of 27 tons per sq. in., an elongation of 7 per cent. in 2 in., and a Brinell hardness number of 210.

Tool Steels.—These may be classified into three main categories: (*a*) carbon tool steels; (*b*) special alloy tool steels; (*c*) high-speed steels. The first are steels high in carbon (see Table, p. 183), but containing no alloying elements. They are used for those cutting tools in which the service exacted is not severe, and in which not enough heat is generated at the cutting edge to draw the temper of the steel. The second category includes steels containing relatively small percentages of special alloying elements, such as chromium, vanadium, tungsten, molybdenum, manganese, cobalt, nickel, silicon, etc. The third group includes those steels containing high percentages of tungsten, cobalt, or molybdenum, with small percentages of other alloying elements, e.g. vanadium, chromium, and manganese, designed for cutting metals, etc., at high speeds in machine tools. Typical compositions of various classes of tool steels with their purposes are given in the tables in this section.

One of the most widely used of the special alloy tool steels is the oil-hardening tool steel of non-shrinking type used for making dies, plugs, gauges, taps, and master tools. This steel is of tungsten-chromium-manganese type, and is designed to harden in oil. It gives an average hardness, after hardening, of 834 diamond and approximately 90 scleroscope. If hardened at 760–780° C., i.e. the lowest temperature to obtain efficient hardness, a slight contraction in length may be expected. This will be less than one-thousandth of an inch per inch. At rather higher hardening temperatures, a slight expansion will occur, again less than one-thousandth inch per inch. An increase in length results in a corresponding decrease in thickness, and vice versa. After being hardened, the steel should be tempered at 200° C. for artificial ageing if required. The limits of growth given above will hold good, and by this means the steel will be artificially aged.

Stellite.—Stellite is a cutting alloy, the average composition of which is 2 per cent. carbon, 22 per cent. tungsten, 45 per cent. cobalt, 25 per cent. chromium, 1·3–2·0 per cent. iron. It is designed for cutting tools, and is superior in cutting power to even the best high-speed steel for certain purposes, though, being a cast alloy, it lacks the toughness of the highest-quality super-high-speed steels. It is extremely hard (600 Brinell up to 700° C.), and cannot, therefore, be sawn with the hacksaw, but must be cut with a thin abrasive wheel of suitable grit and grade.

Tips of the metal are usually brazed or welded to the ordinary steel shank, being afterwards ground to the desired tool form. The alloy cannot be forged or heat treated, and is most useful for cutting materials of highly abrasive type. In general, tools tipped with stellite need less clearance (6°) and rake (10° for steel, 6° for cast iron) in order to yield a lip angle capable of supporting the cutting edge. Rigid support is particularly necessary for the tools in order that the shank may not bend under the heavy cutting pressures or the tool chatter at the nose and flake off. Stellite resists nitric acid. It may be used as a solid tool in small sections. In some instances it is applied direct to the tool shank by melting a rod of the metal in the oxy-acetylene flame, no flux being required.

STEELS FOR STEEL CASTINGS

Type of Steel	Uses
0·10% Carbon max.	For dynamo magnet cases, such as motor cases, rotors, magnet wheels, pole-pieces, etc., for electrical purposes.
0·15% Carbon	For traction frames, etc.
0·20% Carbon	General constructional and industrial uses.
0·30% Carbon	General constructional and industrial uses where high strength is required.
0·40% Carbon	For wearing surfaces.
0·60% Carbon	Die blocks, hammer tups, hammer and press tools, anvils, etc.
0·25% Carbon-manganese	For transmission gears and similar parts where toughness is desired combined with wear resistance.
0·20% C. manganese-molybdenum 0·30% C. manganese-molybdenum	For parts subject to severe shock and stress as in dredging and excavating machinery.
0·20% Carbon-molybdenum 0·30% Carbon-molybdenum	For parts of super-heaters and steam plant where high pressures are encountered, e.g. steam chests, turbine casings, etc.
0·50% Carbon-chromium	For wearing parts such as liners, etc., for crushing and grinding plant, gear blanks, etc.
0·70% Carbon-chromium-molybdenum	For wearing parts of crushing, grinding, and pulverising plant giving high wear resistance and a considerable degree of toughness.
0·80% Carbon-chromium	For wearing parts of ball, tube, and rod mills, wash-mill harrows, etc., where high resistance to wear is required but where less shock is encountered.
Nickel-chromium Nickel-chromium-molybdenum	For parts of lifting machinery, excavators, winches, gears, and smaller parts where high strength and toughness are desired.
25% Nickel	Non-magnetic steel for switch gears, etc. Easily welded.
12–14% Manganese	For wearing parts of crushing, grinding, and pulverising machinery, e.g. crusher jaws, crushing rolls, gyratory crusher cones and mantles, pulveriser hammers, tramway and railway trackwork, dredger parts, excavator pins and bushes, etc.
12–14% Chromium	Hydraulic and steam plant, and particularly for valves, etc., where corrosion attack is encountered and is not excessive.
16–20% Chromium, 2% Nickel	For those parts subject to greater corrosion attack than above, and where the stresses encountered are fairly high.
18/8 Nickel-chromium	For severe corrosion attack, such as in chemical plant, etc. Also for ornamental purposes, e.g. taps, shop fittings, ship fittings.

STEELS FOR STEEL CASTINGS—*cont.*

Type of Steel	*Uses*
18/8/1/1 Nickel-chromium . .	To resist severe corrosion attack and to resist weld decay and intergranular corrosion. Also for heat-resisting parts subject to temperature not exceeding 800° C.
18/8/4 Nickel-chromium-molybdenum	For certain chemical plant of a specified nature, e.g. sulphuric acid, acetic acid, ammonium chloride.
25% Chromium, 15% Nickel .	For parts that are required to stand fairly high temperatures, but not exceeding, say, 1050° C.
28% Chromium	Rabble arms and rabble blades in roasting furnaces. Great resistance to corrosion and scaling even against gases containing sulphur in various forms. It has adequate strength at high temperatures. Can be well recommended where the temperature is more or less constant. Where repeated heating and cooling are encountered, causing severe internal stresses and consequent cracking, use either the 25/15 or the 65/20 type.
35% Nickel, 18% Chromium .	For parts that are required to stand high temperatures up to 1150° C. It has excellent non-scaling properties as well as high strength values at elevated temperatures.
65% Nickel, 20% Chromium .	For carburising boxes, retorts, oil-burner parts and other equipment subjected to high heat and fluctuating temperatures.

Cemented Carbide Tools.—Tungsten carbide is made from a powdered alloy sintered and moulded into tips, which are afterwards brazed on to high-quality mild-steel shanks. It cannot be forged, and the form can, therefore, be modified only by grinding with special wheels. It is extremely hard and much more brittle than high-speed steel, and its main application is to cutting steels, and relatively low-tensile materials, e.g. cast iron and non-ferrous metals, which it will cut at extremely high speeds. It will also last longer between grinds. A light cut at high speed on these materials is its special purpose. Steel may be economically cut with it, but a special grade is used. Where chatter is inevitable, tungsten-carbide tools should not be used.

Feed must not be irregular. Firm support near the cutting edge is essential. Vibration in the machine or piece being machined must be completely eliminated. There must be no end movement or lift in the main spindle bearings. The driving belt or motor must yield enough power without slipping of belt or clutch.

Standard shapes of tools have been evolved, and there is a standard-size range for each shape. Special tools can be made to drawings. The normal grade of carbide is always supplied unless otherwise indicated. For chilled cast-iron rolls and sometimes for brass, a special chill grade is manufactured. In ordering, give the purpose and the tool number as specified in the makers' tool list, indicate clearly whether the complete tool or only the tip is required, and state the cutting rake required. If needing tools not standard, send a drawing showing what is required.

For brazing tips to shanks copper is advised, fluxed with unfused borax.

Shank steel has usually 0·4–0·5 per cent. carbon. Brazing furnace should be at 1150–1200° C., with a reducing atmosphere. The tip should not be struck directly by the flame. Heating must not be unduly prolonged, or the braze will be made unsound. A gas furnace with excess of gas may be used, or an electric furnace with a hydrogen atmosphere. The oxy-acetylene torch may also be used.

Brazing Tungsten-carbide Tips.—Mill each tool shank to match the actual tip. Carefully clean both tip and shank, removing all grease. Carbon tetrachloride is the best cleansing agent. Petrol is unsuitable and paraffin useless. For large-section tools set the tip in place on the shank, after a sliver of electrolytic copper with a small amount of unfused borax have been laid on. Then transfer the entire assembly to the furnace. Do not place a cold tip directly into a fierce heat or it will crack. When the copper slightly liquefies, move the tip a little on its seating to ensure a satisfactory joint. Then remove the tool from the furnace and press the tip gently into place. Dip the tool in powdered electrode carbon or charcoal to ensure slow cooling without contact with the air.

An alternative method is to preheat the shank to 800–1000° C, withdraw the tool, and clean the seat with a wire brush. Borax, copper, and tip are then placed in position until the copper melts, and the procedure already outlined is followed.

The oxy-acetylene torch may be used with the same technique for small-section tools. This eliminates time lag caused by the need to light the furnace, and facilitates the local heating of small and multi-tipped tools. Cool off in charcoal as before.

Grinding Tungsten-carbide Tools.—Wet grinding is recommended, but if dry grinding is unavoidable do not let the tip grow too hot, and on no account cool suddenly with water, the most frequent cause of cracks. Do not press too hard on the alloy when grinding. Only light pressure is needed if the right wheel is used. Obtain full working instructions from the wheel makers. Do not grind the tool upside down. Always present the cutting edge to the wheel in such a way that the wheel revolves into and not away from the edge.

Diamond Grinding Wheels.—These are strongly recommended in grinding tungsten carbide for economy and fine finish. They remove stock rapidly, but

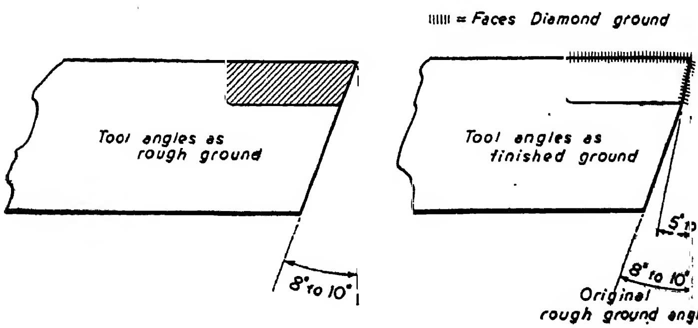


Fig. 5.—Method of grinding tungsten-carbide-tipped tools.

should not be used for rough grinding. The tip and shank should first be rough ground on a coarse, free-cutting wheel, and the cutting edge of the tip diamond ground as in Fig. 5. This gives flat cutting faces free from rounded edges; smooth edges quickly and easily produced and free from grinding cracks; and extremely rapid tool resharpening.

The recommendations given on the next page should be regarded as approximate only, and are to be modified according to local conditions.

SPEEDS AND FEEDS FOR TUNGSTEN-CARBIDE TOOLS

Material	*Rough Turning. Ft. per min.*	*Finish Turning. Ft. per min.*	*Cutting Angles*			
			Roughing		*Finishing*	
			C.	*T.R.*	*C.*	*T.R.*
			°	°	°	°
Steel:						
28–35 tons						
Black bar	500–600	1000–1500	5	3	4	0
Rough forgings	350–400	—	5	3	—	—
Clean metal	600–1000	1000–1500	5	8	4	0
Castings	300–400	500–750	5	0–3	4	0–2 neg.
35–45 tons						
Black bar	450–550	1000–1200	5	3	4	0
Rough forgings	300–400	—	—	—	—	—
Clean metal	600–750	1000–1200	5	5	4	0
Castings	250–350	400–500	5	0	4	0–2 neg.
40–45 tons						
Black bar	300–400	800–1000	5	0–3	4	0
Rough forgings	250–350	—	5	0–3	—	—
Clean metal	500–600	300–400	5	0 or neg.	4	0–2 neg.
55–65 tons						
Stampings	250–350	600–800	5	0–2 neg.	4	0
Forgings	225–300	—	5	0–2 neg.	—	—
Clean metal	450–550	600–800	5	0–3	4	0
High-speed						
Annealed	100–200	200–300	4	3	4	0
Chrome-nickel, 65–90 *tons*						
Stampings	120–200	250–400	4	0–2 neg.	4	0
Forgings	120–200	250–400	4	0–2 neg.	4	0
Clean metal	250–400	350–500	4	0	3	0
Stainless						
Castings	70–100	100–150	4	2 neg.	4	2–3 neg.
Bar	150–250	250–300	4	3	4	0
12% *Manganese*	10–25	25–50	4	0–3 neg.	3	0–3 neg.
Cast Iron:						
200 Brinell	180–220	350–450	5	8	5	3
Close-grain	160–200	250–350	5	5–8	5	3
Cast centrifugal	120–160	250–350	5	8	5	3
Chromium	120–160	200–250	5	3–5	5	3
Malleable	180–220	350–450	5	8	5	3–5
10% nickel	20–30	25–45	4	0	4	0
Pearlite	20–30	25–45	4	0	4	0
Iron:						
Wrought	300–400	400–600	5	8	5	8
Chilled	15–20	20–35	4	0	4	0
Copper	500–800	750–1000	5–6	15	5	13
Cupro-nickel	350–500	400–600	5	8	5	8
Brass:						
Soft	750–900	750–1000	5	3	5	3
Hard cast	400–600	500–800	4	3	5	3
Bronze	400–600	500–800	4	3	5	3
Gunmetal	400–600	500–800	4	3	5	3
Bronze:						
Aluminium	300–450	400–600	4	3	4	3
Admiralty	300–450	400–600	4	3	4	3
Manganese	300–450	400–600	4	3	4	3

SPEEDS AND FEEDS FOR TUNGSTEN-CARBIDE TOOLS—*cont.*

Material	*Rough Turning. Ft. per min.*	*Finish Turning. Ft. per min*	*Cutting Angles*			
			Roughing		*Finishing*	
			C.	*T.R.*	*C.*	*T.R.*
			°	°	°	°
Aluminium	1000–2000	Any speed above 1000	5–6	15	5	15
Alloys	600–800	750–900	5	15	5	15
Silicon	400–600	500–750	4–5	15	4–5	15
Zinc-base alloys	600–800	750–900	5	15	5	15
Duralumin	600–800	750–900	5	15	5	15
Plastics	400–600	800–1000	20–25	3 neg.	20–25	3 neg.
Erinoid	400–600	800–1000	20–25	3 neg.	20–25	3 neg.
Hard rubber	600–800	800–1500	20–25	3 neg.	20–25	3 neg.
Porcelain	20–30	30–50	4	3 neg.	4	3 neg.
Glass	60–90	80–100	4	5–8	4	3
Slate	80–120	100–120	4	3	4	3
Marble	80–120	100–120	4	3	4	3

Flame Hardening.—A method of case-hardening as a result of locally heating parts by an oxy-acetylene or other oxy-fuel blowpipe, swiftly followed by water or other type quenching through specially designed water jets. Invented by A. E. Shorter, M.B.E. The case produced may range from approximately 0·0125 in. to about ¼ in., according to method of application and type of steel. Normal depth of hardening is standardised for convenience at 0·1–0·125 in.

In ordinary case-hardening, the composition of the steel is changed. In flame hardening or "Shorterising," it is not. The four different methods are: (1) the job remains fixed, but burner and quenching jets move in relation to it; (2) burner and jets remain stationary, the job moving; (3) burner and quenching equipment move longitudinally while job rotates; (4) job rotates quickly and is heated, after which the blowpipe is removed and quenching carried out. Machines for methods (1), (2), and (3) are termed "progressive," those for (4) "consecutive." Rate of heating is governed by burner dimensions and speed of traverse. Quenching is controlled by distance at which jets follow burner and by volume of coolant provided.

Steels for flame-hardening range from 0·3–0·6 per cent. carbon, but medium carbon alloy steels may also be hardened. Molybdenum is a valuable element in alloy steels for flame hardening. Heat-treated steels giving a maximum stress of 60–65 tons per sq. in. for the core are not suitable for flame hardening.

Parts must be stress-relieved before treatment by normalising, annealing, or hardening and tempering, which last is best for parts liable to shock. No specific size limit for flame-hardened parts exists. As compared with ordinary case-hardening, flame hardening is more advantageous for hardening parts too large for ordinary furnaces, and those in which distortion cannot be avoided by the older methods. Flame hardening produces virtually no distortion. Other advantages are: (*a*) high degree of surface hardness given; (*b*) core remains unchanged; (*c*) core may be heat treated for toughness and ductility first, and hard case produced afterwards without any weakening of the core; (*d*) case merges gradually into core, and hardness persists over about 80 per cent. of the hardened area's depth.

Parts must be tempered or stress relieved as soon as possible after quenching. Heat in an ordinary heat-treatment furnace or oil bath to 175–205° C. and cool in air or in the furnace. Do not burn or overheat the steel in the course of the process, i.e. do not bring the flame too close to the part or unduly prolong the heating period. Shorter flame hardening has been successfully applied to gear rings, brake drums, tyres, axles, cams, straightening and bending rolls, shafts, crankshafts, and journals.

STEELS SUITABLE FOR FLAME HARDENING

Composition					*Diamond Hardness No.*	*Brinell No.*
C	*Mn*	*Cr*	*Ni*	*Mo*		
0·3 –0·35	0·5–0·8	—	—	—	300–400	300–400
0·35–0·4	0·5–0·8	—	—	—	400–500	390–465
0·4 –0·45	0·5–0·8	—	—	—	500–650	465–570
0·45–0·5	0·5–0·8	—	—	—	650–700	570–600
0·5 –0·55	0·4–0·8	—	—	—	700–800	600–660
0·55–0·6	0·4–0·8	—	—	—	800–850	660–680
0·5 –0·6	0·4–0·8	—	—	—	700–850	600–680
0·35–0·5	1·6–1·9	—	—	0·3–0·4	650–750	570–630
0·35–0·45	0·5–0·8	—	1·0–1·5	0·3–0·4	550–800	500–660
0·35–0·45	1·2 max.	—	1·0	—	550–700	500–600
0·25–0·35	0·35–0·75	0·3	2·75–3·0	—	470–550	440–500
0·35–0·45	0·5 –0·8	0·3	3·25–3 75	—	550–700	500–600
0·25–0·35	0·45–0·7	0·5–1·0	3·0 –3·75	0·25	500–700	465–600
0·32	0·56	0·72	2·56	0·42	650	570

Induction Hardening.—A method of surface-hardening steel parts that comprises placing a steel bar within a wound coil or inductor carrying adequate alternating current. The portion of the bar within the magnetic field of the inductor becomes heated, and if enough power is supplied, the heat developed suffices to bring the surface zone of the bar up to the critical temperature of the steel within a few seconds. Accurate control of form and dimension of the hardened area, as well as of physical and metallurgical characteristics, are obtained by the use of special apparatus and technique.

The heated zone is quenched by pressure jets of cooling liquid ejected through holes in the inductor block. Thus, quenching is carried out without permitting air cooling, and handling from heating position to cooling position is eliminated. The process is known as the "Tocco" process, being first invented by The Ohio Crankshaft Co., of Cleveland, Ohio.

Heating must be very swift to prevent heat conductivity causing transfer of heat to adjacent areas, and to produce a better metallurgical structure of the hardened area and a more suitable bond between hardened area and core. Five or six seconds is the average heating time for a 3-in.-diam. cylindrical section. In core and fillets, the original structure remains unchanged.

The process hardens the bearing surfaces of shafts while leaving the ductility unimpaired for the rest of the shaft. The structure produced withstands wear and abrasion. Hardness is uniform from bearing to bearing and from crankshaft to crankshaft. Advantages of the process are: (*a*) a short time cycle; (*b*) small space required; (*c*) reduction of handling costs; (*d*) low cost per unit hardened. Standard steels may be used, as well as various cast materials, but they must be such as will develop the desired physical and metallurgical properties in the areas treated, i.e. will respond properly when heated to the critical temperature and quenched.

Originally designed for hardening the bearing areas on crankshafts, the process has now been applied with success to camshafts. Cams and eccentrics may be hardened to Rockwell C.60, while the gear, which is subject to shock loads, is hardened to only Rockwell C.52. This differential hardness is handled in the same operation. The machine design allows of holding the camshaft in position between steady rests, so that distortion is held usually to within 0·007-in. indicator runout. The equipment may be employed for operations other than surface hardening, e.g. localised heating, brazing, and soldering. It comprises a hardening machine or cabinet, usually designed for a specific job, a motor generator set to produce the necessary high-frequency current, and automatic control apparatus.

IRON CASTINGS

Types of Iron.—There are nine terms denoting some form of iron—(1) white iron, (2) malleable iron (see p. 207), (3) grey iron, (4) semi-steel (see p. 207), (5) pearlitic iron, (6) high-strength iron, (7) austenitic cast iron, (8) graphitic steel, (9) alloy cast iron.

White iron is that in which the carbon is all in the combined form and the fracture has a white (not silvery) appearance. In malleable cast iron, the combined carbon of white cast iron has been transformed into an amorphous, uncombined condition by special heat treatment, i.e. to free or "temper" carbon. Grey iron has its carbon all in the form of graphite flakes, giving a typical grey fracture. Pearlitic iron is cast iron possessing a matrix of pearlitic type, i.e. containing 0·6–0·9 per cent. combined carbon. "High-strength" iron merely indicates an iron capable of giving a tensile strength of more than 18–20 tons per sq. in. Austenitic cast irons are grey cast irons with small alloy additions, usually nickel, to produce special magnetic and corrosion-resisting properties. Graphitic steels cover both irons and steels in which all the carbon occurs as graphite as a result of suitable choice of treatment and composition. Alloy cast irons are those with additions of alloying elements such as nickel, molybdenum, chromium, etc., to give special properties.

Manufacture of Cast Iron.—Most grey iron is made in a type of miniature blast furnace known as the cupola, which is a vertical, cylindrical furnace comprising steel plates lined with refractory bricks, provided with a charging door and possessing tuyères through which the air enters. By way of the charging door the fuel, usually coke, is introduced, and on this a layer of iron is placed, with similar successive alternations of fuel and iron, or, if a flux (limestone) is used, it is loaded on to the fuel. Cupola furnaces vary in dimensions from 42 to 84 in. internal diameter, and will melt from 5 to 25 tons per hour. Charge varies. A typical figure is 1500 lb. for a 48-in. cupola. Air blast is not preheated, though heating is advocated and in certain districts is actually carried out. Coke proportion varies also, and may be anything from 1 : 7 to 1 : 12 of iron. Air consumption is about 30,000 cu. ft. per ton melted. Blast pressure may range from 8 to 30 oz.

Silicon and manganese oxidise, and this results in a higher sulphur percentage, particularly if low-grade coke is employed. A proportion of the pig iron is frequently remelted in a reverberatory furnace, and mixed with the iron from the cupola either in advance of or during casting. Remelting may also be done in the basic arc furnace, which provides ample fluidity, elimination of sulphur, and close control of chemical composition.

Cupola Melting Facts.—0·75 multiplied by melting-zone area of cupola in square inches equals iron charge in pounds. 1 lb. coke melts 8 lb. iron. 125 cu. ft. of air needed to transform 1 lb. ordinary coke to carbon dioxide. About 30,000 cu. ft. of air needed to melt 1 ton iron. Melting rate: 8 lb. iron per square inch cupola area. Tuyère area for 36-in. cupola equals one-fifth cupola area. For larger cupolas the area will be nearer to one-tenth, e.g. for an 84-in. cupola.

Moulding and Casting Practice.—The iron when melted is poured by way of a taphole into iron buckets lined with refractory material, and known as ladles. These may serve to cast the iron directly into the moulds, or alternatively may feed smaller vessels known as shanks from which the moulds receive their metal. Higher carbon contents of the iron produce greater fluidity. Silicon and phosphorus also promote increased fluidity. To produce particular forms of castings patterns are prepared, which are imprinted in the sand and, when taken out, leave an impression into which the iron flows when poured. An allowance has to be made for the inevitable cooling contraction when these patterns are made. Contraction cavities are prevented by the use of "risers" or cylindrical openings specially made at the top of the mould. These are filled with molten iron, and serve as a reservoir from which metal descends to fill up the cavities that would otherwise be left by contraction on cooling.

Moulding sands must be heat-resistant, so that they do not fuse at high temperatures. They must be porous, to allow air and gas to escape during casting, and they must be capable of easy removal from the cooled casting while leaving

a sharp, clean surface. Plasticity, adhesiveness, and cohesiveness are other properties required. The grain size of the sand is important. Uniform size with angular shape make for greater porosity but not for a clean, smooth surface.

The face of the mould taking the wash of hot metal is formed with facing sand, while the sand comprising the supporting sand or body of the mould is termed black sand or floor sand.

There are four main moulding methods: (*a*) green-sand moulding; (*b*) dry-sand moulding; (*c*) loam-sand moulding; (*d*) chill moulding.

(*a*) The moulds are made from sand containing different substances designed to make it more resistant to heat. This sand is damp enough to cohere when heated. That part of the mould surface designed to meet the wash of molten metal may be flame dried to dry out the surface only. Green-sand moulding is mainly used for making small castings.

(*b*) When the sand has been closely packed in the mould, the entire mould is stove-dried, and a much finer sand is employed for the face. As a rule, clay is introduced into the sand to act as a binder, or may actually constitute an original ingredient of the sand.

(*c*) Loam-sand moulding is moulding without the use of patterns, and calls for great skill. The sand has to be very plastic, and embodies a much higher percentage of clay than ordinary moulding sand. The moistened loam is applied to brick supports roughly built up to the mould form, and strengthened by iron plates, etc. The mould is dried before casting. Like dry-sand moulding, this method is used for large castings.

(*d*) Chill moulds are made throughout of metal and are employed when considerable numbers of identical castings are desired.

Straw, manure, and coal dust are mixed with clayey sands to increase porosity. Wire rods are inserted in the sand to make vent holes, and must not be too close to the internal surface of the mould. Cores are often made of sea sand blended with oil. The mould surface is painted with foundry blacking to produce a smoother casting surface by closing up the pores in the facing sand through which the metal might enter.

Castings of complex design and unequal section may suffer from uneven contraction, causing unequal stresses and possibly tears or cracks. Chills (iron or steel bars) are placed in the mould close to the larger sections, so as to chill the parts concerned and thus balance up the cooling rate for the entire piece.

Centrifugal Casting.—In making cast-iron pipes, centrifugal casting is largely taking the place of the methods described. The molten metal is quickly run into swiftly revolving moulds, cooled by water, and made from an alloy steel. After being cast, the pipes are annealed in continuous furnaces when taken from the moulds.

Foundry Sand Mixtures.—For small castings, two parts of Mansfield sand, 1–2 parts of old sand, 1–15 parts powdered coal. A good facing sand is made up of 20 parts new sand, 20 parts road sand, 3 parts manure, and 5 parts powdered coal.

Effect of Common Elements on Cast Iron.—Silicon decomposes the combined carbon to form ferrite and graphite, and transforms white iron into grey. Manganese does not greatly modify the mechanical properties of grey iron, but must be present to the extent of 0·5–0·8 per cent. to combine with undesired sulphur. Sulphur has no marked deleterious effect so long as it does not exceed 0·16–0·18 per cent. Higher sulphur in the absence of a compensating amount of manganese stabilises the cementite and causes chill. Phosphorus produces a very fluid iron.

Heat Treatment of Iron Castings.—The effect of cooling down in a mould is to produce certain stresses that lead to strains in the casting. To remove these it is necessary to anneal the casting by heating it to a relatively high temperature and allowing it to cool down slowly. This not only relieves the stresses set up but also has a softening effect on the iron (see pp. 218 and 219).

Cast-iron Growth.—The effect of heating and cooling frequently repeated on cast iron is to cause an expansion or growth, which may attain relatively considerable proportions. This growth is not identical in amount over the entire mass of the casting, since the heating that causes it is itself not uniform. In consequence, considerable warping and even disintegration of the iron may occur.

Excessive silicon appears to promote growth, so that where repeated heatings are likely, it is better to employ for the purpose a casting made from an iron low in silicon. Growth may sometimes be prevented by the introduction of alloying elements, e.g. chromium, into the iron (see Table below).

Physical Constants for Cast Iron.—Contraction allowance for making patterns: $\frac{1}{8}$ in. per ft. for linear contraction of grey iron; $\frac{3}{16}$–$\frac{1}{4}$ in. per ft. for white iron.

Coefficient of expansion for grey iron is 13×10^{-6} per °C. for the range 0–500° C., or $10{\cdot}5 \times 10^{-6}$ per °C. in the range 0–100° C.

Density: 6·95 (approximately) g. per c.c. for high-carbon grey iron; 7·35 g. per c.c. for low-carbon grey iron. To convert to pounds per cubic foot, multiply by 62·428.

Thermal conductivity: about 0·11 cal. per sq. cm. per ° C.

Mechanical Properties.—Tensile strength: 9–27 tons per sq. in. Modulus of rupture is calculated by means of the following formulæ:

$$\text{Round bar} = \frac{2{\cdot}546 \times LS}{D^3}. \qquad \text{Rectangular bar} = \frac{3 \times LS}{2 \times BH^2}.$$

Here, S is the span, L the ultimate or breaking load, B the width of the bar, H its height, and D its diameter.

Ratio of shear strength to tensile strength is 1·64–1·01 per unit of tensile, according to the strength of the iron. Compression strength in relation to tensile strength is 4·5 to 2·5 per unit, according to the strength of the iron. Brinell hardness: grey iron, 130–210; white iron, 321–534; alloy grey iron, 600 and over; alloy white iron, 600 and over.

Compositions of Grey-iron Castings.—Below are characteristic compositions of some commercial grey irons used for making cast parts:

Total Carbon	*Si*	*Mn*	*P*	*S*	*Ni*	*Cr*
%	%	%	%	%	%	%
3·0	1·3–1·5	0·7	0·5	0·1–0·15	—	—
3·46	2·44	0·76	0·71	0·057	—	—
3·27	2·05	0·92	0·176	0·110	—	—
3·25	2·25	0·65	0·15	0·10	—	—
3·60	1·75	0·50	0·80	1·08	—	—
3·30	2·00	0·50	0·35	0·10	—	—
3·20	1·44	0·91	0·170	0·108	1·12	—
2·75	2·25	0·80	0·10	0·09	—	—
3·25	2·25	0·65	0·15	0·10	0·75	0·30
2·75	2·25	0·70	0·15	0·08	—	0·50

Machinability of Cast Iron.—Castings are machinable with increasing difficulty according to their type. The order of machinability of the various types, placing the most machinable first, is as follows: (*a*) ferritic irons; (*b*) pearlitic irons; (*c*) mottled irons; (*d*) white iron. Of these, the white iron presents an extremely difficult machining problem. Machinability is much influenced by surface condition, a normally quite machinable iron being often rendered most difficult to turn or plane because of the presence of sand particles burned into the surface layers. In such instances the cuts must be deep enough to get right under the skin of the casting.

Influence of Temperature on Cast Iron.—Cast iron should not be employed for making any pressure vessel likely to be used at temperatures exceeding 230° C., and the maximum pressure should not go above 250 lb. As a rule, cast iron (unalloyed) is not suitable for use at temperatures exceeding 450° C. Up to 430° C. little falling off in tensile strength is observable, and the same is true of

Brinell hardness and fatigue limit, while compressive strength is not much altered within this range. Wear resistance is good at reasonably high temperatures, but if parts have to be used in conditions of high dynamic stress at high temperature cast iron should not be used. Special heat-resisting alloy irons are made (see p. 216 and Table on p. 218).

Corrosion of Cast Iron.—Corrosion resistance of cast iron is much greater than that of steel. Dilute sulphuric acid has a severe corrosive effect, but strong sulphuric acid does not attack cast iron unless it becomes diluted by the absorption of moisture from the air. Hence, cast-iron pipe lines handling sulphuric acid must be air-tight. Dilute nitric acid also corrodes grey iron, but high-silicon iron withstands the attack. Cast iron must not be used for strong hydrochloric acid, but may be safely employed for alkaline solutions and caustics. There is a wide range of corrosion-resisting alloy irons (see Table on p. 218).

Heat Treatment of Plain Cast Iron.—To anneal, heat to 425–540° C., hold for ½ hour to 5 hours according to mass, and cool slowly in the furnace. To soften for machining, heat to 760–815° C. The effect of this treatment is to lower the strength of the iron to a small extent. White or mottled irons as cast may be annealed to produce grey irons of superior strength. The treatment recommended for this purpose is to heat to 925–955° C. and hold for 1½–3 hours, then cool to 745° C. for 3 hours, and either quench in oil and temper, air cool, or cool down gradually in the furnace.

To quench and temper cast iron as a means of obtaining a greater resistance to wear and abrasion, heat to a point above the critical temperature (approximately 790–845° C.); quench; then heat to a temperature above 175° C. for tempering. Quenching is usually in oil, but water may sometimes be employed.

Nitriding Cast Iron.—Economical nitriding (see p. 138) of cast irons designed to withstand a high degree of wear is feasible. The castings are heated in the presence of anhydrous ammonia gas at temperatures ranging from 510 to 595° C. for from 20 to 90 hours. A characteristic composition for this purpose is: Total carbon, 2·61 per cent.; silicon, 2·58 per cent.; manganese, 0·61 per cent.; sulphur, 0·07 per cent.; phosphorus, 0·10 per cent.; chromium, 1·69 per cent.; and aluminium 1·43 per cent.

Cast iron may also be flame hardened (see p. 214).

REFRACTORY MATERIALS

Refractory materials are those designed to withstand extremely high temperatures, and are used either for lining furnaces, crucibles, ladles, and other receptacles of molten metal, or for flues, nozzles, etc. Furnace linings in metallurgical work are usually made of materials previously calcined, but some refractories are used raw. A good refractory must be infusible at the operating temperature, must not crack at this temperature, and must not suffer from warping or loss of size, because such defects might lead to the destruction of a complete furnace arch or roof. They must not be readily attacked and eroded by molten metal or slag, and have to be able to withstand some degree of pressure.

There are three classes of refractories—acid, basic, and neutral. Acid include sand, ganister, and certain fireclays. Basic refractories have no silica, and basic oxides predominate. Typical basic materials are dolomite, magnesite, and lime. Neutral refractories have an accurate balance of acid and basic ingredients, or are made of chemically neutral substances. Examples are chrome bricks, graphite, carborundum, and certain fireclays.

A typical fireclay comprises 50 per cent. silica, 30 per cent. alumina, 12 per cent. water, etc., 4 per cent. iron oxide, 2 per cent. lime, 2 per cent. magnesia. Another acid fireclay is made up of 80 per cent. silica, 1 per cent. alumina, 5 per cent. water, 2 per cent. iron oxide, 7 per cent. lime, 0·7 per cent. magnesia, 4·3 per cent. organic matter.

Fireclay and magnesia chemically react upon one another at high temperatures, and may have layers of neutral (chrome) bricks interposed between them to prevent this.

As a rule, a refractory is regarded as one designed to withstand temperatures above 1580° C.

SEGER CONE TEMPERATURES OF REFRACTORIES [1]

°C.	Material	°C.	Material
2180	Chromite	1795	Bauxite clay
2165	Magnesite bricks	1785	Bauxite brick
2050	Chromite bricks	1750	Pure silica
2010	Pure alumina	1700	Ganister; silica brick
1840	Best fireclay brick	1690	Pure silica with 14·5 per cent. alumina
1830	Kaolin	1650	Pure silica with fine grains; fire-clay brick, normal grade
1820	Bauxite	1595	Refractory porcelain
1790	Pure silica with 63 per cent. alumina; mullite		

[1] These are the temperatures at which a Seger cone of the material begins to bend over (see p. 169).

Heat-resisting Cement.—While these cements, designed principally for repairing worn furnace linings without having to shut down the furnace for a complete relining, are usually regarded as proprietary materials, with compositions known only to their makers, it may be taken for granted that they are composed of varying percentages of refractory materials such as fireclay, ground firebricks, and Portland cement or water glass. Two typical mixtures are: fireclay and plumbago, to which water is added to make a paste; litharge, 6 lb., newly calcined lime, 4 lb., kaolin, 2 lb., using linseed oil to mix. This cement is designed to stop up openings in or repair melting pots, and is fire-resistant only. The amounts used may be varied as desired, so long as the proportions remain the same.

PICKLING AND CLEANING CAST PARTS

Pickling.—Castings, rods, sheets, bars, etc., particularly those of ferrous material, are often coated with a film of oxide, especially when they have been hot rolled. In order to prepare the material for cold working, this layer of oxide must be removed, and the method frequently adopted is to *pickle* the iron or steel in an acid solution. Not only does this chemical process remove the scale, etc., from the surface, but it also serves the useful purpose of showing up defects, such as cracks, seams, laps, etc., and may even be employed for this object alone.

The first essential is a thorough cleaning of the part or piece to be pickled, using a hot alkali solution, followed by careful rinsing. Pickling temperatures should not exceed 65–70° C. In such instances acid concentration in the pickling solution may be increased to 10–12 per cent. If the solution is heated to 65–90° C., as was at one time customary, the solution strength should not exceed 10 per cent. acid concentration, falling to 6 per cent. if time and capacity permit. Seven per cent. concentration is normal with hydrochloric acid.

Pickling Acids.—There are numerous pickling acids, of which commercial hydrochloric acid is now the most commonly used, having largely superseded sulphuric acid. This is generally used cold. Stainless steels may be pickled in nitric acid, and this acid may also be employed to oxidise scaled surfaces in order to make the pickling process easier. Hydrofluoric acid quickens up the pickling process, and is also effective in ridding castings of sand.

Inhibitors may be included in the pickling bath to hinder the solution from corroding oxide-free surfaces without delaying the pickling action. Typical inhibitors are pyridine, quinoline or quinidine, and similar synthetic chemicals, but many other materials of organic type have been used, including cabbage leaves and wheat bran, sulphite cellulose liquor and waste animal substances.

Pickling Brittleness.—The effect of hydrochloric acid on steel may be harmful, if the material is subjected to a cold-working operation too soon after the process. It appears to be caused by the giving off of hydrogen gas as a result of the chemical reaction between the solution and the steel, with the result that nascent hydrogen penetrates into the steel and causes brittleness. This effect is purely temporary, and is partly prevented by the use of an inhibitor, while it may be quickly eliminated if the steel is heated to 100–150° C. or left untouched for a few days after pickling. Pickling defects also include pitting, caused by excessive pickling, by electrolytic action, or by rolled-in scale, etc. Blistering of the steel's surface may also result, by reason of the generation of hydrogen gas. Too protracted a pickling period may cause a rough and porous surface, combined with bad colour and diminution in dimensions and weight of the piece. Pickling hardened steels may cause cracks on the pickled surface owing to the relief of surface stresses, so that high-speed steel and other hardened tools, etc., should not be pickled.

Sand and Shot Blasting.—Sand is projected by an air or other blast on to the surface of parts to be cleaned. Shot blasting is similar, except that the particles projected are chilled iron shot. The modern method is to employ a wheel revolving at high speed, which flings out the shot by centrifugal force. (The centrifugal process is not suitable for sand, which is too light.) Air-pressure blasts may be of direct pressure, gravity, or suction types. Pressures employed range from 60 to 100 lb. per sq. in. Non-ferrous metals need 10–60 lb. The exact pressure is determined by the character of the work and the amount of cleaning required.

Nozzles are to-day being lined with tungsten carbide to withstand wear, and should last about 300 hours. A new $\frac{3}{8}$-in. nozzle should allow approximately 211 cu. ft. of air, needing 40·5 h.p. for its production, to flow at 90 lb. pressure. Sand wears out nozzles more readily than does shot.

TABLE OF NOZZLE DIMENSIONS, PRESSURES, AND H.P. REQUIRED

Diam. in in.	*Pressure in lb.*	*Air Flow in cu. ft. per min.*	*H.P.*	*Diam. in in.*	*Pressure in lb.*	*Air Flow in cu. ft. per min.*	*H.P.*
$\frac{1}{8}$	20	7·70	0·63	$\frac{1}{4}$	60	67·00	10·25
$\frac{1}{8}$	30	10·00	1·03	$\frac{1}{4}$	70	76·00	12·77
$\frac{1}{8}$	40	12·30	1·50	$\frac{1}{4}$	80	85·00	15·47
$\frac{1}{8}$	50	14·50	1·99	$\frac{1}{4}$	100	103·00	21·32
$\frac{1}{8}$	60	16·80	2·57	$\frac{5}{16}$	20	48·17	3·95
$\frac{1}{8}$	70	19·00	3·19	$\frac{5}{16}$	30	62·89	6·48
$\frac{1}{8}$	80	21·20	3·86	$\frac{5}{16}$	40	76·60	9·36
$\frac{1}{8}$	100	25·73	5·33	$\frac{5}{16}$	50	90·70	12·43
$\frac{3}{16}$	20	17·10	1·40	$\frac{5}{16}$	60	105·00	16·07
$\frac{3}{16}$	30	22·50	2·32	$\frac{5}{16}$	70	119·00	20·00
$\frac{3}{16}$	40	27·50	3·26	$\frac{5}{16}$	80	133·00	24·10
$\frac{3}{16}$	50	32·80	4·49	$\frac{5}{16}$	100	161·00	33·82
$\frac{3}{16}$	60	37·50	5·64	$\frac{3}{8}$	20	69·00	5·66
$\frac{3}{16}$	70	43·00	7·22	$\frac{3}{8}$	30	90·00	9·27
$\frac{3}{16}$	80	47·50	8.65	$\frac{3}{8}$	40	110·00	13·42
$\frac{3}{16}$	100	57·88	11·98	$\frac{3}{8}$	50	130·00	17·81
$\frac{1}{4}$	20	30·80	2·53	$\frac{3}{8}$	60	151·00	23·10
$\frac{1}{4}$	30	40·00	4·12	$\frac{3}{8}$	70	171·00	28·73
$\frac{1}{4}$	40	49·10	5·99	$\frac{3}{8}$	80	191·00	34·76
$\frac{1}{4}$	50	58·20	7·97	$\frac{3}{8}$	100	232·00	47·90

Tumbling Castings.—A method of removing adherent sand, scale, etc., from iron and steel castings by placing them in a revolving barrel, together with a number of loose slugs or metallic parts, or an abrasive material. The rolling

motion and the impact of the loose slugs, etc., upon the parts serves to dislodge the adherent matter, and is also claimed to have a beneficial effect on the castings, since the hammering of the surface by the slugs during the process relieves strains of internal type and also makes the surface more uniform.

Modern tumbling eliminates dust, etc., by exhausted-air circulation, while charging and unloading are both carried out automatically, as well as the sorting out of the cleaned parts from the slugs, etc.

Tumbling barrels are usually of wood for brass and nickel-silver small parts; cast metallic barrels are used for heavier castings and for some work involving the use of a fine abrasive; sheet-metal barrels are designed for heavy castings with sharp edges that might damage a cast metallic barrel; non-ferrous barrels are used when the effect of, for example, cast iron on the parts might be to cause discoloration, as with high-quality brass castings. They are also used for tumbling castings in acids capable of attacking ferrous metals. Tumbling may be either wet or dry. If wet, a water pipe is used fixed to run into the open head of the barrel. Oil is sometimes used.

Barrels may be vertical for small parts or horizontal for large or long castings. The latter tumble more uniformly than the vertical barrels, and will take big and weighty loads, being superior for rough cleaning. There may be more than one compartment in the barrel. Open-ended horizontal barrels are designed for automatic working.

Tumbling Abrasives.—These include sharp sand, cinders, slag, broken glass, emery, corundum, granite chippings, pumice, limestone, sea sand, wood blocks, slugs of metal, punchings, steel balls, or steel wool.

ABRASIVES FOR TUMBLING

Material Cleaned	*Abrasive Used*	*Type of Work*
Brass; soft metals	Pumice	Finish smoothing
Hard metals	Emery, corundum	Finish smoothing
Screw machine products	Dry sawdust	Brightening
General metals	Silica, chalk, lime, rouge, leather scrap, meal, felt, hardwood	Brightening
General metals	Slugs, punchings, steel balls, steel wool	To clean out corners, keyways, etc.

Barrel speed ranges from 20 to 60 r.p.m. Load should be 40–50 per cent. of barrel capacity. Castings above 6 in. long are not usually tumbled. Times depend on state, form, and hardness of the surface of the casting. Softer metals are tumbled more quickly.

TIME REQUIRED FOR TUMBLING

Material	*Tumbling Time Required*
Brass, cast	10–15 hrs.
Bronze castings	10–15 hrs.
Malleable-iron castings	30–40 hrs.
Grey-iron castings	70–80 hrs.
Stampings, steel	1–100 hrs. (av. 48 hrs.)
Screw machine parts, steel	1–100 hrs. (av. 48 hrs.)
Forgings	4–5 hrs. (80–90 per cent. clean)

Barrel Burnishing.—Revolving parts in a suitable barrel together with a burnishing agent, so as to produce a lustrous surface. The process is used when it is more economical than manual polishing, or where the form and dimensions of the part make burnishing impossible by any other method. Round steel balls are used as the burnishing medium. Where angles, corners, slots, keyways, or other indentations smaller than the burnishing-ball diameter are to be dealt with, or there is an unusual configuration of the surface, media of different form, e.g. cones, cylinders, ball cones, etc., may be used.

The parts must be carefully cleaned before operation, and their surface must be already in as smooth a state as possible.

Burnishing Times

Material	*Time*
Nickel	1 hr.
Brass	1 hr.
Steel	¼–100 hrs.
Chromium plate	2 hrs.
Nickel silver	1 hr.
Aluminium diecastings	1 hr.
Zinc diecastings	1 hr.

Burnishing Lubricants.—Soap, soap bark, molasses, stale beer, alkalis, alkaline cleaners, cyanide, cream of tartar.

Burnishing Barrels.—Usually of cast metal, wood-lined; cast steel unlined; cast iron with welded sheet-steel linings. Brass, diecastings, etc., are usually burnished in brass-lined barrels.

MAKING FOUNDRY PATTERNS

Pattern Materials.—Most patterns in Britain are made from Quebec or Columbian yellow pine, and in special instances from baywood or mahogany. Loose metal patterns are also employed when only a small number of identical parts have to be made.

Shrinkage Tables.—It is quite common to find in technical handbooks tables of "pattern makers' shrinkage," in which contraction data are given for different pattern lengths. It should be pointed out that these tables should not be used in pattern making for steel-casting production, because contraction data are *not* governed by length. The contraction in inches per foot or in percentage of length is identical for both 12 in. in length and 60 in. in length. Instead of relying on these tables, it is better either to allow the steel founder to construct the pattern, or at all events to submit a drawing to the foundry, and ask for guidance on contraction allowances.

The reader should note that solid contraction varies in extent with the type of steel of which the casting is to be made, and also with the design of the casting, since mould resistance to normal casting shrinkage is considerably affected by the form of the piece. Moreover, the moulding method adopted may also call for alterations in contraction allowances. Thus, one and the same casting pattern may involve a number of varying contraction allowances. Two different steel foundries may need quite different contraction allowances. Hence the advisability of allowing the steel founder to make the pattern, and of ignoring seductive shrinkage tables that have only a hypothetical value.

Standard Pattern Colours.—In the United States, a standard system of colour markings for foundry patterns has been adopted, and this system is commonly used in Great Britain, though individual designers may depart from the system in some minor degree. In the United States the colour system is as follows: (*a*) all pattern surfaces denoting casting surface to be left in the rough

are painted black; (*b*) those surfaces to be machined are painted red; (*c*) seats of and for loose pieces are marked by red stripes on a yellow background; (*d*) core prints and seats for loose prints are painted yellow; (*e*) stop-offs are shown by diagonal black stripes on a yellow base. The colours are usually obtained by mixing suitable cheap paints with varnish or shellac so as to yield the kind of coating required.

In British pattern shops, it is quite common to paint the entire pattern black, and paint over the surfaces required coloured, or the pattern may be given a coat of yellow varnish, other colours being painted.

Types of Patterns.—There are six types of pattern equipment: (1) single loose patterns of wood or metal; (2) gated patterns of wood or metal; (3) metal match-plate patterns; (4) wood cope or drag patterns; (5) metal cope or drag patterns; (6) special equipment.

(1) These are employed for small lots only, because they readily distort if a damp atmosphere exists, while they are also easily damaged by use. They are the most economical for big castings. For making complex or highly accurate castings they are better mounted, and this gives a sharper casting at a more economical cost.

(2) These may be employed for small-quantity production of uncomplicated castings, but are also liable to warp and break.

(3) These are for considerable numbers of small castings. They produce accurate castings in a short production time, so that their higher first cost is outweighed by the economies they render possible.

WEIGHTS OF PATTERNS AND CASTINGS

Pattern Material (Patt. wt. 1 lb.)	*Weight in lb. when cast in*				
	Cast Iron	*Zinc*	*Copper*	*Yellow Brass*	*Gun-metal*
Baywood	8·0	8·0	10·0	9·8	10·0
Cedar	11·5	11·4	14·5	14·0	14·5
Mahogany	8·0	8·0	10·0	9·8	10·0
Maple	10·0	9·8	12·5	12·0	12·4
White pine	14·0	14·5	18·0	17·5	17·8
Quebec yellow pine	13·0	12·6	16·0	15·5	16·0

Steel castings are slightly, but only slightly, heavier than iron, the difference being about 1 lb. in 100 lb.

(4) and (5) These are suitable for medium to large castings, and give high output. When made of metal, cope and drag patterns can be used for weighty castings of which large numbers are required, and for machine moulding of castings.

Machine-finish Allowances.—This is governed by: (1) The class of steel; (2) the casting's form and the surface to be machined; (3) the dimensions of the piece; (4) the pouring position; (5) the liability to pull or distort; (6) the method of machining and set up; (7) the degree of smoothness required on the machined surfaces. There are no standard finish allowances, each casting presenting a problem of its own. Usually, allowances vary from virtually nil to $\frac{3}{4}$ in.

Draft.—This is the taper that has to be allowed on all vertical pattern faces to allow the pattern to be withdrawn from the mould without damaging the mould walls. The draft is governed by the dimensions of the casting, the way in which it is made, and whether moulding is by hand or machine. Machine moulding calls for only minimum draft. In green-sand moulding, the internal surfaces need more draft than the external. Given normal conditions, the draft advised is at least $\frac{1}{16}$ in. per foot.

Location Points.—Locating points to be employed by the machine shop should be clearly marked on drawings. Place them on the same side of the parting line. They should be so placed as not to be affected by core movement, or cope or

drag movement. Keep as far apart as casting dimensions allow, to ensure accuracy. Dimensions with no finish allowances to be held to close limits are the correct place from which to begin development of tooling fixtures.

Parting Lines for Patterns.—Make in the horizontal plane to render moulding easier.

Useful Data.—Steel castings weigh on average 490 lb. per cubic foot, or 0·283 lb. per cubic inch. The approximate weight of a casting may be estimated from the weight of the pattern, by reference to the table on the previous page.

LINEAR CONTRACTION IN CAST-STEEL BARS ALLOWED TO CONTRACT FREELY

Carbon Per cent.	*Total Contraction Per cent.*	*Carbon Per cent.*	*Total Contraction Per cent.*
0·08	2·47	0·45	2·35
0·14	2·46	0·55	2·31
0·35	2·40	0·90	2·18

LINEAR CONTRACTION IN ALLOY CAST-STEEL BARS ALLOWED TO CONTRACT FREELY

Type of Steel	*Total Contraction Per cent.*	*Type of Steel*	*Total Contraction Per cent.*
0·35 Carbon	2·40	0·25 Vanadium	2·32
1·32 Manganese	2·38	1·35 Mn, 1·15 Si	2·35
3·0 Nickel	2·40	1·46 Ni, 1·24 Mn	2·37
1·03 Chromium	2·34	1·41 Mn, 0·37 Mo	2·32
1·39 Copper	2·35	1·41 Mn, 0·16 Va	2·33
0·39 Molybdenum	2·33	2·88 Ni, 0·91 Cr	2·27

Density of Molten Steel. — Density and specific volume of cast steel are closely allied to thermal expansion of steel. When t (temperature) is comparatively small, $D_t = \frac{D_0}{(1 + 3\alpha t)}$ where D_t is the density at temperature 0^0, and α is the coefficient of linear thermal expansion. This expression may be found helpful when calculating density at high temperatures.

DENSITY OF IRON-CARBON ALLOYS

Carbon Per cent.	*Melting-point °C.*	*Density at 1600° C. in g. Per c.c.*	*Carbon Per cent.*	*Melting-point °C.*	*Density at 1600° C. in g. Per c.c.*
0·0	1533	7·158	0·9	1464	6·863
0·1	1514	7·061	1·0	1458	6·844
0·2	1503	7·003	1·5	1422	6·798
0·3	1494	6·963	2·0	1382	6·725
0·4	1486	6·939	2·5	1341	6·662
0·5	1480	6·920	3·0	1290	6·587
0·6	1477	6·905	3·5	1232	6·499
0·7	1474	6·891	4·0	1170	6·385
0·8	1469	6·877			

EFFECT OF MASS UPON DENSITY OF CAST STEEL

Section-inches	*Density-grams Per c.c.*	*Composition*
Centre 1 in.	7·838	0·25 per cent. carbon. 0·63 per cent. manganese. 0·23 per cent. silicon.
,, 3 in.	7·831	
,, 5 in.	7·823	
,, 8 in.	7·812	

Power Required to Drive Wood Saws.—The approximate power required to drive circular saws when the timber is being fed by hand is 1–1¼ b.h.p. per inch depth of cut.

FORGE WELDING QUALITIES OF STEEL

Carbon, per cent.	*Property*	*Comments*
1·58	Unweldable	Not often employed.
1·38	Can be welded	Employed for hard tools.
1·10	Fairly weldable	Used for chisels, etc.
0·88–0·6	Easily weldable	Used for files, etc.
0·62–0·38	Readily weldable	Used for rails, tyres, etc.
0·38–0·15	Will not temper	Used for boiler plate.
0·15–0·05	Will not temper	Alternative for iron.

Protecting Steel against Case-hardening.—A mixture of 1 part of barium sulphate, 2 parts white silica, 3 parts kaolin, mixed with a solution of silicate of soda dissolved in water until a density of 1·400 is attained. Cover the parts to be protected with the paste thus formed. The mixture is effective up to temperatures not exceeding 900° C.

CUTTING ANGLES FOR EDGE TOOLS

Degrees	*Purpose*
90–70	Machine tools on cast iron, shears, punches, and other hand tools.
70–60	Machine tools on moderately hard metals, hand or chipping chisels on metal.
60–50	Hand-turning tools on hard wood or ebonite.
50–40	Cutting edges of axes, adzes, choppers, for wood.
40–30	Mallet-struck tools, carving, graving, and similar tools, for wood.
30–25	Plane irons, spokeshaves, draw knives, for wood.
25–20	Woodworking tools under hand pressure.
20–18	Carving, pruning, and slicing knives.
18–16	Surgeons' knives and penknives.
17–16	Hand razors.
16–15	Safety razors.

CUTTING ANGLES FOR LATHE TOOLS

Material	*Front Clearance Angle, Degrees*	*Cutting Angle, Degrees*
Hard cast iron . .	4	80
Medium cast iron .	4	75
Soft cast iron . .	4	70
Hard forged steel .	4	70
Medium forged steel .	5 or 6	67½
Soft forged steel .	10	62½

SPEEDS AND FEEDS FOR HIGH-SPEED STEEL TOOLS
(18 per cent. Tungsten), Feet per Minute.

Depth per Cut	*Feed per Rev.*	*Soft Steel*	*Medium Steel*	*Hard Steel*	*Soft C.I.*	*Medium C.I.*	*Hard C.I.*
$\frac{1}{16}$ in.. .	$\frac{1}{16}$ in.	140–150	100–110	45–50	100–110	50–55	35–40
$\frac{3}{16}$ in.. .	$\frac{1}{16}$ in.	100–110	75–80	35–40	80–90	40–45	23–30
$\frac{5}{16}$ in.. .	$\frac{1}{8}$ in.	70–75	45–50	25–30	55–65	30–35	20–25
$\frac{3}{8}$ in.. .	$\frac{1}{8}$ in.	55–60	35–40	18–20	50–55	20–25	18–22

Tensile Strength of Steels.—The approximate tensile strengths of steels may be ascertained by multiplying the Brinell hardness number by certain factors. The following may be found useful: for chrome steel, multiply by 0·242; for nickel-chrome steel, by 0·240; for nickel steel, by 0·239; for vanadium steel, by 0·235; for carbon steel, by 0·232.

MILLING-CUTTER FEEDS AND SPEEDS

Material	*Type of Cutter*	*Feet Surface Speed per Minute.*	
		Carbon-steel Cutters	*High-speed Steel Cutters*
Cast Iron . .	Face mill . .	40–50	80–100
Cast Iron . .	Spiral Mill . .	45–60	—
Mild Steel . .	Face Mill . .	40–50	80–100
Mild Steel . .	Spiral Mill . .	50–60	—
Tool Steel . .	Annealed . .	30–40	60–80
Brass . .	. . . .	80–100	150–250

Stainless-steel Temper Colours.—Cutlery stainless steel resists oxidation, so that more heat is needed to produce a given temper colour than for ordinary steel. The following table gives approximate temperatures only:

Tint	*Appears at °C.*	*Tint*	*Appears at °C.*
Light straw . .	300	Blue . . .	535
Dark straw . .	350	Grey blue . .	595
Reddish purple .	400	Greenish blue . .	705
Bluish purple . .	455		

TAPPING DRILLS

Tap Size	*Drill for Whitworth Standard Threads*	*Drill for Whitworth Gas Threads*
In.	*In.*	*In.*
$\frac{1}{8}$	$\frac{3}{32}$	$\frac{5}{16}$
$\frac{1}{4}$	$\frac{3}{16}$	$\frac{27}{64}$
$\frac{5}{16}$	$\frac{1}{4}$	—
$\frac{3}{8}$	$\frac{19}{64}$	$\frac{9}{16}$
$\frac{7}{16}$	$\frac{23}{64}$	—
$\frac{1}{2}$	$\frac{13}{32}$	$\frac{11}{16}$
$\frac{9}{16}$	$\frac{15}{32}$	—
$\frac{5}{8}$	$\frac{33}{64}$	$\frac{25}{32}$
$\frac{11}{16}$	$\frac{37}{64}$	—
$\frac{3}{4}$	$\frac{5}{8}$	$\frac{29}{32}$
$\frac{13}{16}$	$\frac{11}{16}$	—
$\frac{7}{8}$	$\frac{47}{64}$	$1\frac{1}{16}$
1	$\frac{27}{32}$	$1\frac{1}{8}$
$1\frac{1}{8}$	$\frac{61}{64}$	—
$1\frac{1}{4}$	$1\frac{1}{16}$	$1\frac{15}{32}$
$1\frac{3}{8}$	$1\frac{11}{64}$	—
$1\frac{1}{2}$	$1\frac{19}{64}$	$1\frac{25}{32}$
$1\frac{5}{8}$	$1\frac{3}{8}$	—
$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{15}{16}$
2	$1\frac{23}{32}$	$2\frac{5}{32}$
$2\frac{1}{4}$	$1\frac{15}{16}$	$2\frac{13}{32}$
$2\frac{1}{2}$	$2\frac{3}{16}$	$2\frac{25}{32}$
$2\frac{3}{4}$	$2\frac{13}{32}$	$3\frac{1}{32}$
3	$2\frac{41}{64}$	$3\frac{9}{32}$

Cutting Compound for Drilling Hard Spots.—A useful solution is: 1 part powdered sulphur, 1 part cylinder oil, 2 parts castor oil.

Tap Flutes for Various Metals.—Below is a table giving the advised number of flutes for taps for certain materials and sizes:

Size	*Aluminium*	*Steel*	*Cast Iron*
In.			
$\frac{1}{4}$	2	2	2 or 4
$\frac{5}{16}$	2	2 or 3	2 or 4
$\frac{3}{8}$	2 or 3	3 or 4	3 or 4
$\frac{7}{16}$	2 or 3	3 or 4	3 or 4
$\frac{1}{2}$	2 or 3	3 or 4	4
$\frac{5}{8}$	4	4	4

YIELD POINTS OF CUTLERY STAINLESS STEEL AND STAINLESS IRON

Tempering Temp. °C.	*Yield Point Tons, Stainless Steel*	*Yield Point Tons, Stainless Iron*
200	84·8	66·0
300	92·8	—
400	95·2	62·8
500	90·0	66·0
550	73·0	46·0
600	49·0	43·6
650	46·8	39·2
700	42·0	34·4

To Prevent Lead from Sticking to Steel in the Lead Bath.—Coat the parts with a mixture of common whiting and wood alcohol. Water may be employed instead of alcohol, but in such a case the coating must be thoroughly dried, or the steam formed as soon as the moist coating is dipped in the lead will give rise to spattering.

Protecting Blind Holes or Recesses from Hardening.—Smooth holes may be stopped up with clay, or clay mixed with asbestos pulp or wood-charcoal dust. Always dry the tool before hardening. For threaded holes, form roughly a tube in asbestos pulp, place it in direct contact with the thread, fill up the remaining hole with clay so as to force the tube on to the thread. Seal hermetically with an outer coat of clay.

Making Steel Wool.—One method is to pass heavy steel wire from a spool over a bench to another spool on to which it is wound by power. Cutters mounted in a framework over the bench dig into the wire, which is kept taut against them. The cutter edges are ground on a coarse abrasive wheel to roughen their edges. The method produces the desired fine-steel threads.

Blueing Steel Parts.—Plunge the parts when cleaned into a mixture of 10 parts nitre (saltpetre) to 1 part of black oxide of manganese by weight, heated to 425–455° C. Keep the mixture in a cast-iron pot. The parts are best kept in a wire basket. Allow to stay in the nitre for 5–10 minutes. The longer period gives the darker blue. Then quench in water at 50–65° C. When dry, cover with raw linseed oil and drain.

Preventing Scale in Hardening.—Add approximately 5 per cent. sulphuric acid to the hardening bath (water) to clean scale from steel parts. Wash thoroughly after the quench.

MECHANICAL WORKING OF STEELS

Forging.—The process by whose means steels or other metals are changed in form by being hammered or squeezed mechanically, usually while hot. Mechanical forging involves the use of a hammer driven by steam or compressed air. In drop forging, the hammer head and die or anvil have a form such that the required forging shape is easily obtained. The solid-steel block must first be reheated to 1000–1250° C. and soaked thoroughly at this temperature, which depends on the quality of steel employed and the dimensions to be achieved by the first reduction. Small ingots are allowed to grow cold before being reheated for forging. Large ingots are generally transferred while hot to reheating furnaces.

The main functions carried out by forging hammer or press include : (1) rounding up, cogging, or roughing ; (2) cutting or slicing ; (3) reduction of size ; (4) upsetting ; (5) setting down.

(1) This is designed to regroup the grains of which the steel is composed and at the same time break them down into smaller size, so that an ingot having a rather coarse structure is refined and improved in mechanical strength.

(2) This operation produces stock to the desired length.

(3) Is designed to lengthen the stock while reducing its diameter.

(4) Is an operation whereby the ingot is forged in a direction perpendicular to its longitudinal axis.

(5) Is a method of reducing the cross section of a particular portion only of a piece.

Steels with above 1·0 per cent. carbon are best hot worked for the finish forging operations at or close to their lower critical point.

Other forging operations are piercing, boring, trepanning, boring and expanding. Typical hammer forgings are axles, bars, bolts, bushes, shafts, trunnions, valves, etc.

Forging Equipment.—Hammers are of two types : single acting and double acting. They comprise a die block embedded in foundations ; a steel hammer

or tup running in guides, and striking down vertically upon the anvil, the rod to which the hammer is attached being secured to the end of a piston operating in a cylinder. Single-acting hammers are those in which the hammer falls by gravity alone. Double-acting hammers employ air or steam pressure to increase the weight of the downward thrust. Hammer power is based on weight of the tup, e.g. a 5-ton hammer is that in which tup and rod together weigh 5 tons.

A furnace for heating up the ingot for forging is required, and power-operated shears and circular sawing machines will probably be needed to cut the stock into suitable lengths.

Forging tools include punches, swages, swage blocks, mandrels, vee-blocks, knives, pegs, and tongs, as well as a series of dies and tools for particular operations.

Transportation of forgings from furnace to hammer, and their suspension during operations, may be manual, but if the pieces are over 2 cwts. in weight, a jib crane for medium-sized and an overhead crane for very large pieces may be needed.

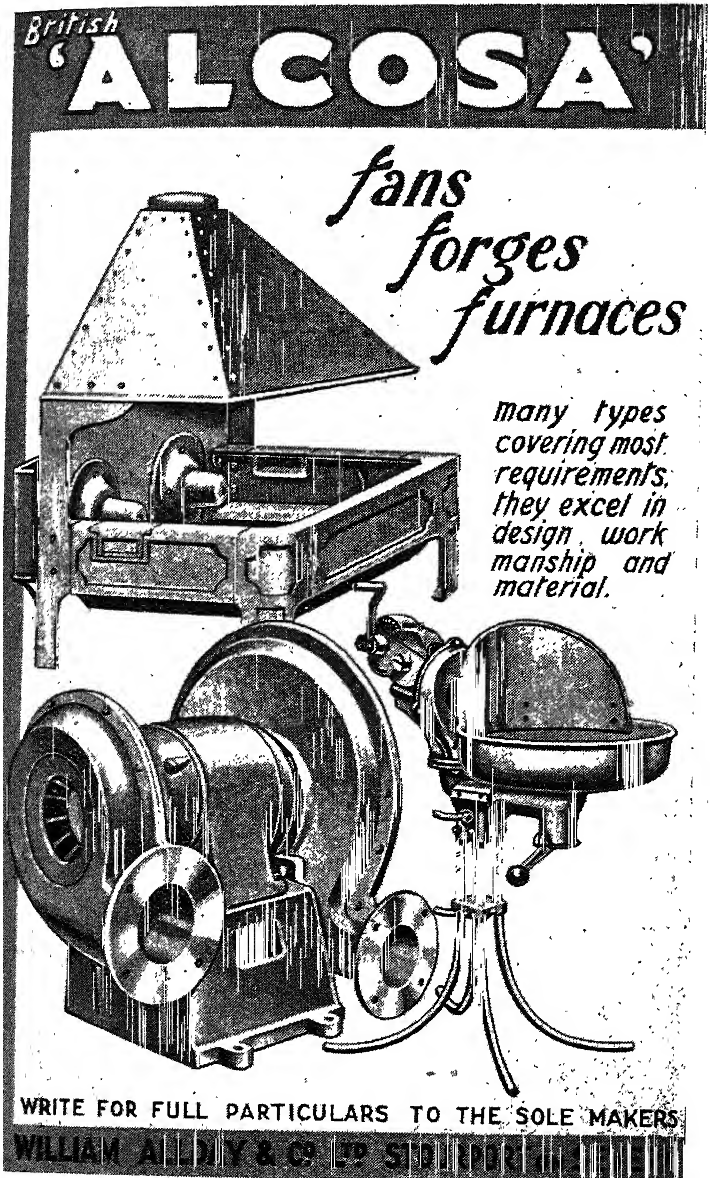
Drop Forging.—This forging process is designed to produce a large quantity of formed forgings identical with one another. It is the stamping or forging of a piece of hot steel stock between dies under a mechanically operated hammer. There are two halves, a top and bottom, to the die, the lower being secured to the anvil block, the upper to the hammer, with which it rises and descends. Fins left after the stroke are removed from the die edges by either (*a*) rotating circular stock in the dies through a small arc, alternating between every few blows, so that the fin is removed as formed ; (*b*) knocking the forging through a die in which is a hole of the same form, so that the fin is stripped away and left behind.

Stock.—Stock for drop forging must not be too bulky, or there will be an undue preponderance of scrap in the form of large fins, while labour required for forging will be excessive. Cracks may also result from the heavier blows needed and from the cooling down of the large fins. A bare sufficiency of metal may mean difficult manipulation to ensure that all the recesses of the die are filled uniformly ; unfilled impressions, with consequent defective form of the forging ; trapping of metal between the dies, thus preventing them from properly closing ; and absence of fins, leading to fracture of hardened steel-die faces as a result of too severe an impact, since the fins tend to absorb some of the force of the blows. Inadequate metal causes imperfect forging shape, because of incomplete filling of die impressions ; and fracture or cracking of dies through absence of fin cushioning effect.

Stock is usually received as bars or billets. It should be so formed and made ready that its flow into the die impressions coincides with the natural flow of the plastic metal under impact, and in particular, from thick sections to thin. Fibre direction is important.

Steels for Drop Forging.—Low-carbon steels (0·2 per cent. carbon) are readily drop forged within a wide temperature range. Higher-carbon steels have less plasticity, and consequently the forging range must be narrower. Stainless steels, high in chromium content, are much less plastic at temperatures above " red heat," and workable inside a much closer temperature range, so that considerably more precaution is needed in operation, while more frequent reheatings are necessary. In Great Britain and America, a steel with about 2·5 per cent. nickel, 0·5 per cent. molybdenum, 0·6 per cent. chromium, is favoured for normal drop-forging dies. For short runs and flat die work, a 0·6 per cent. carbon steel of suitable temper may be used. Where forging temperatures are much higher, and for forging machine and upsetting work, a steel with 8–9 per cent. tungsten, 2·5–3·25 per cent. chromium, and 0·4–0·6 per cent. vanadium, is satisfactory for die blocks. Eschew low-priced and low-grade steels for this work.

Operations in Drop Forging.—These comprise the preliminary work of: (*a*) edging, (*b*) fulling, (*c*) drawing, and (*d*) bending. Edging produces a form suitable for later operations ; fulling compresses the stock in the middle and forces the displaced metal away to the ends ; drawing reduces the cross section except at one end ; bending forms the stock asymmetrically in readiness for the forging of the completed part. A blocking-out operation may be required for complicated drop forgings, and will be intermediate between the preliminary and the finishing operations.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Cutting off of fins is carried out while the forging is still hot, though it may be done cold in some instances. Pickling in dilute hydrochloric acid to remove scale, and tumbling or sand-blasting to produce a good surface, follow. Normalising to remove stresses is also desirable.

Upsetting.—A method of making forged-steel bolts, nails, cap screws, etc., in which the cross section of a piece of stock is enlarged at one end by continually striking that end upon an anvil. The machine employed consists of a massive steel body with two dies, a stationary and a moving. The stock is placed on the stationary die, and the movable die is brought up to it and holds it firmly against the stationary die. A header tool then moves forward and presses the stock into the die impressions, after which the die withdraws. Essentially, the upsetting machine forms the stock by a powerful, continuing, and increasing thrust, and not by a sharp blow.

Rules for Upset Forging.—(1) Maximum length of unsupported metal upsettable in one blow = $3 \times D$ (diameter of stock). In practice, the usual rule is $2\frac{1}{2} \times D$. (2) Where L (length of unsupported stock) is not greater than $3 \times D$, maximum enlargement of cross section upsettable in one blow is $1 \cdot 3 \times D$. (3) Where L is greater than $3 \times D$, but U (upset) not more than $1\frac{1}{2} \times D$, L must not exceed 1D.

Deep Piercing.—Producing a hollowed-out forging by driving a punch into the centre of the stock and at the same time forcing the displaced metal into the shape desired. This produces superior forgings, economises in time and expense, and produces forgings as strong as by any other method of producing hollowed-out parts, but of lighter weight. Tools should not have an included angle of more than 60 degrees.

Cold Heading.—A type of upsetting carried out on cold stock. Two principal methods are used: (1) the single thrust or blow; (2) multiple thrust. The method adopted affects the amount of upsetting. This amount is expressed by the formula $\frac{L}{D}$ = diameter of upsetting, L being the length of stock and D its diameter.

The equipment includes a pair of cylindrical rolls into which the stock is fed. A mechanical knife severs the stock into lengths. The severed stock is then transported mechanically to heading dies, which are fixed, the punches driving forward and backward, and being secured to a driving head. Most cold heading is done by method (2). Dies may be either solid or in halves, the solid dies being used for the shorter parts, which are mechanically ejected from them at the finish of the strokes. Split dies are employed for long parts. They are divided vertically into two steel blocks, in each of whose four faces are machined semicircular grooves. The blocks are reversible when worn, and are opened a trifle at the completion of the final stroke so as to ensure easy ejection of the part.

Cold Heading Steels.—These range from low carbon to stainless, but in practice 0·5 per cent. carbon in the steel should not be exceeded. 3·5 per cent. nickel steel, nickel-chromium steel, austenitic stainless steel, and 25 per cent. chromium/12 per cent. nickel steels have been successfully cold headed. Straight chromium steels are also capable of being manipulated by this method.

Economics of Cold Heading.—Cold heading *v.* hot forging is governed by raw material cost, capacity of plant, length of run, and cost of installing equipment where it is not already installed. There is in addition a dimensional restriction. The maximum diameter is $1\frac{1}{2}$ in., but in practice it is not often that 1-in. diam. is exceeded, the maximum shank length in this diameter being approximately 9 in.

Die Steels for Cold Heading.—Two characteristic steels are: 0·95–1·0 per cent. carbon, 0·2–0·3 per cent. vanadium, 0·25–0·35 per cent. manganese; 0·2–0·3 per cent. silicon; 0·95–1·0 per cent. carbon, 0·2–0·3 per cent. manganese; 0·15–0·3 per cent. silicon. Typical parts made by cold heading include bolts, rivets, valve spring retainers, commutator segments, drum plugs, screws, studs, etc.

Standard Tolerances for Forgings up to 100 lb. (adopted by the Drop Forging Association, 1937).

THICKNESS TOLERANCES IN INCHES

Maximum Net Weight	*Commercial*		*Close*	
	Minus	*Plus*	*Minus*	*Plus*
lb.				
0·2	0·008	0·024	0·004	0·012
0·4	0·009	0·027	0·005	0·015
0·6	0·010	0·030	0·005	0·015
0·8	0·011	0·033	0·006	0·018
1	0·012	0·036	0·006	0·018
2	0·015	0·045	0·008	0·024
3	0·017	0·051	0·009	0·027
4	0·018	0·054	0·009	0·027
5	0·019	0·057	0·010	0·030
10	0·022	0·066	0·011	0·033
20	0·026	0·078	0·013	0·039
30	0·030	0·090	0·015	0·045
40	0·034	0·102	0·017	0·051
50	0·038	0·114	0·019	0·057
60	0·042	0·126	0·021	0·063
70	0·046	0·138	0·023	0·069
80	0·050	0·150	0·025	0·075
90	0·054	0·162	0·027	0·081
100	0·058	0·174	0·029	0·087

SHRINKAGE AND DIE WEAR IN INCHES

Length or Width	*Shrinkage*		*Maximum Net Weight*	*Die Wear*	
	Commercial + or —	*Close + or —*		*Commercial + or —*	*Close + or —*
1 in.	0·003	0·002	1 lb.	0·032	0·016
2 in.	0·006	0·003	3 lb.	0·035	0·018
3 in.	0·009	0·005	5 lb.	0·038	0·019
4 in.	0·012	0·006	7 lb.	0·041	0·021
5 in.	0·015	0·008	9 lb.	0·044	0·022
6 in.	0·018	0·009	11 lb.	0·047	0·024
For each additional inch add	0·003	0·0015	*For each additional 2 lb.* add	0·003	0·0015
For example:			*For example:*		
7 in.	0·021	0·011	18 lb.	0·050	0·026
12 in.	0·036	0·018	21 lb.	0·062	0·031
18 in.	0·054	0·027	31 lb.	0·077	0·039
24 in.	0·072	0·036	41 lb.	0·092	0·046
36 in.	0·108	0·054	51 lb.	0·107	0·054
48 in.	0·144	0·072	71 lb.	0·137	0·069
60 in.	0·180	0·090	91 lb.	0·167	0·084

MISMATCHING TOLERANCE IN INCHES

Maximum Net Weight	*Commercial*	*Close*
1 lb.	0·015	0·010
7 lb.	0·018	0·012
13 lb.	0·021	0·014
19 lb.	0·024	0·016
For additional 6 lb. add:	0·003	0·002
For example:		
37 lb.	0·033	0·022
55 lb.	0·042	0·028
79 lb.	0·054	0·036
97 lb.	0·063	0·042

FILLET AND CORNER TOLERANCES

Maximum Net Weight	*Commercial*	*Close*
0·3 lb.	$\frac{3}{32}$	$\frac{3}{64}$
1 lb.	$\frac{1}{8}$	$\frac{1}{16}$
3 lb.	$\frac{5}{32}$	$\frac{5}{64}$
10 lb.	$\frac{3}{16}$	$\frac{3}{32}$
30 lb.	$\frac{7}{32}$	$\frac{7}{64}$
100 lb.	$\frac{1}{4}$	$\frac{1}{8}$

QUANTITY TOLERANCES

Number on Order	*Over-run*	*Under-run*
1 to 2	1 piece	0
3 to 5	2 pieces	1 piece
6 to 19	3 pieces	1 piece
20 to 29	4 pieces	2 pieces
30 to 39	5 pieces	2 pieces
40 to 49	6 pieces	3 pieces
50 to 59	7 pieces	3 pieces
60 to 69	8 pieces	4 pieces
70 to 79	9 pieces	4 pieces
80 to 99	10 pieces	5 pieces
100 to 199	10 per cent.	5·0 per cent.
200 to 299	9 per cent.	4·5-per cent.
300 to 599	8 per cent.	4·0 per cent.
600 to 1,249	7 per cent.	3·5 per cent.
1,250 to 2,999	6 per cent.	3·0 per cent.
3,000 to 9,999	5 per cent.	2·5 per cent.
10,000 to 39,999	4 per cent.	2·0 per cent.
40,000 to 299,999	3 per cent.	1·5 per cent.
300,000 +	2 per cent.	1·0 per cent.

DRAFT ANGLE TOLERANCES IN DEGREES

	Drop Forgings		*Upset Forgings*	
	Outside	*Inside Holes*	*Outside*	*Inside Holes*
Nominal angle	7	7 or 10	3	5
Commercial limits	0 to 10	0 to 13	0 to 5	0 to 8
Close limits	0 to 8	0 to 8	0 to 4	0 to 7

Rolling.—One of the principal methods of mechanically reducing the section of a metallic ingot, etc. The stock is heated to the correct temperature in a furnace, and then passed between two rolls, power-driven in opposite directions and carried by a heavy supporting frame. Each set of rolls in its frame or housing makes up a stand, and two or more stands constitute a train. Slabs, plates, and sheets are rolled with plain rolls, but blooms, billets, bars, and sections are rolled with grooved rolls.

Rolling Mills are classified as: (1) cogging; (2) plate; (3) sheet; (4) bar; (5) rod and wire. Rolling is less expensive than forging, and is suitable for a large variety of purposes.

Rolls.—Usually cast to the required shape and machined to size. Hot rolls are of cast iron or steel. Sand-cast iron rolls are mainly employed for rough rolling, and eliminate surface scale more quickly than chilled iron rolls, which are used for finish rolling. Alloy-steel rolls are used when a smooth, hard surface is desired. Alloy-iron rolls may also be used for this purpose.

Pressure on the material during rolling is governed by reducing the distance between the rolls through the housing screws set on top of the housings. Sheets and bars are manually dealt with; for larger pieces, a mechanical manipulator will be required.

Principles of Rolling.—Extent of reduction in cross section (draught) is governed by actual cross-sectional form, type of steel being rolled, and rolling temperature. Alloy steels are less plastic than carbon steels.

Entering angle must not be below 30 degrees, or the steel will not go through the rolls.

Metal goes through the rolls faster than it enters them, and this increase in speed must be allowed for. It is controlled by thickness of section, roll diameter, and degree of reduction.

Rolling may be either vertical or horizontal. Horizontal rolls increase width and slightly decrease thickness. Vertical rolls have the effect of decreasing width and slightly increasing thickness. For some work both types of rolling may be required.

In rolling plates, the slab is first rolled in such a way that its length equals the plate width desired; it is then turned through 90 degrees and rolled to the desired thickness. This is termed cross rolling. Rolling is done between 900 and 1250° C.

Cold Rolling.—This is mostly restricted to flat bars, sheets, and strip. The raw material is sheet steel over 12 gauge in thickness, hot rolled, and pickled to remove scale. Low-carbon steels are cold rolled after pickling; higher-carbon steels need an annealing treatment. Tandem mills, single-stand reversing mills, Steckel mills, and cold sheet mills are principally used.

Annealing for Cold Rolling.—Heat to a suitable temperature in a sealed cast-iron box filled with cast-iron chips. Hold at temperature for about 4 hours, and allow to cool down in the furnace.

Effects of Cold Rolling.—Marked increase in tensile strength up to about 10–15 per cent. reduction; thereafter no great change. Slightly sharper increase in yield point and hardness. Elongation declines slowly, but recovers after 16 per cent. reduction in cross section, and rises afterwards up to 60 per cent.

reduction. Exact figures are governed by annealing temperature. Higher annealing temperatures decrease final tensile strength, yield point, and Rockwell hardness.

Erichsen Cupping Test.—Designed to show the ability of sheet and strip to be drawn. A bulge is made in the material by a convex die slowly pressed into it by a manually operated ram until fracture takes place. The depth of the convexity at the moment of fracture is read in millimetres, and the value represents the drawability and quality of the strip. Values vary with thickness. In a modified version of this test, the material is firmly held between dies during the forming of the bulge.

Cold Rolling Austenitic Stainless Steels.—Corrosion resistance of these steels is decreased by cold rolling, but can be restored by reheating to approximately 1100° C. and cooling in the air, or even by quenching.

Pressing.—Resembles machine forging (upsetting), but employs a mechanical or hydraulic press to squeeze the metal steadily until it acquires the desired form. The mechanically operated press is used for small or medium-sized parts, and the hydraulic press for large parts. Copper, brass, etc., are usually dealt with by the mechanical press, which has a capacity ranging from 200 to 2,000 tons. The stock is placed on a bottom die, which may be either solid and stationary, or divided into fixed and movable sections. In the former case the press is known as single acting, since one vertical stroke suffices for the work. If there is not only a downward stroke but an extra movement raising a movable die up to a fixed die before finishing the downward stroke, the press is termed double acting, and is in effect a vertical forging machine.

The hydraulic press ranges in capacity from 200 to 15,000 tons. It employs only solid dies. It will forge steel ingots from 12 to 70 in. and over, but is truly economical only for ingots above 24-in. section, as below this size it shows no economic advantage over the mechanical press.

For hot pressing, pressures range from 14 to 34 tons per square inch, and for cold pressing, from 50 to 100. Maximum operating pressure is computed by $A \times Y$, where A is the area over which contact extends at its greatest point, and Y is the yield point of the material.

Cold Pressing.—Pressure is affected by area of surface over which it is to be applied; plasticity of the metal; extent of deformation desired. The more complex cold pressings are manufactured from steels up to 0·25 per cent. carbon, but if an adequate number of intermediate normalisings and annealings are given, complex parts may be pressed from steels up to 0·45 per cent. carbon.

Steels over 0·2 per cent. carbon must be either normalised, annealed, or subcritically annealed (spheroidised, see p. 189). The spheroidising temperature is usually between 670 and 680° C.

Smooth surfaces are desirable for cold pressings, because polishing costs are reduced thereby, and painting, lacquering, plating, or cellulose spraying will be easier to perform and yield better surfaces.

Stretcher Strains.—Surface disfigurements following a linear pattern produced when ductile steel is cold pressed and unevenly work hardened. The variation in hardness may equal 5 per cent. It can be remedied by passing the material through a levelling or flattening machine while at the same time slightly stretching it. Not more than 24 hours should elapse between this operation and the final pressing, or the steel will go back to its unsatisfactory condition.

Strain Ageing.—When cold-pressed steel is allowed to stand for a considerable length of time at normal temperatures, or even at temperatures up to 300° C., it becomes harder, less ductile, and less able to withstand impact. This condition, which may be highly undesirable, may be remedied by heating the steel to approximately 670° C. and slowly cooling.

Cold Pressing Stainless Steels.—These steels may be cold pressed, but require extra care, as they rapidly work harden. Softening temperature depends on the quality of the steel. A straight chromium steel (0·3 per cent. carbon, 13 per cent. chromium) requires to be softened at 750° C. approximately. Austenitic stainless steels (18 per cent. chromium, 8 per cent. nickel) need air cooling or even water quenching from temperatures above 1000° C.

STEELS FOR COLD PRESSINGS

P.G. Mark	*Nomenclature*	*Chemical Composition*				
		C	*Si (max.)*	*S (max.)*	*P (max.)*	*Mn*
101	Dead-soft Steel .	0·07–0·12	0·10	0·05	0·05	0·40–0·70
102	Special dead-killed, dead-soft Steel	0·07–0·12	0·04	0·04	0·04	0·35–0·60
102A	0·10–0·15 Carbon Steel	0·10–0·15	0·15	0·05	0·05	0·40–0·70
102B	0·15–0·20 ,,	0·15–0·20	0·15	0·05	0·05	0·40–0·70
103	0·20–0·25 ,,	0·20–0·25	0·15	0·05	0·05	0·40–0·70
104	0·25–0·30 ,,	0·25–0·30	0·20	0·05	0·05	0·40–0·70
105	0·30–0·35 ,,	0·30–0·35	0·20	0·05	0·05	0·40–0·70
106	0·35–0·45 ,,	0·35–0·45	0·20	0·05	0·05	0·40–0·80
107	0·20 Carbon High-manganese Steel	0·18–0·23	0·20	0·05	0·05	1·4–1·7

Lubricant for Cold Pressing.—Good-quality, sodium-base soap, 5 per cent.; castor oil, 25 per cent.; finely ground chalk, 45 per cent.; water, 25 per cent.

Extrusion.—Forcing metal through a hole in a die so as to produce a highly elongated section of uniform volume and reduced cross section. The action is a pushing one, not a pulling, as in cold drawing. The process is primarily used for making stainless and seamless steel and non-ferrous tubing. Presses have a capacity of 200 to 2000 tons, while hydraulic draw benches have a capacity of 75 to 300 tons. The process may also be applied to making chromium-steel valves. Mechanical presses may also be employed. Hot extrusion only is practised for steel.

(as made by the Parkgate Iron and Steel Co., Ltd.)

Condition in which supplied[1]	Typical Tests: Tensile strength tons/sq. in.	Typical Tests: Elongation per cent. in 4 in.	Typical Applications
N at 910° C. A at 910° C.	24·6 23·5	41 44	General cold-pressing work for automobiles, colliery equipment, miscellaneous hardware, etc.
N at 910° C. A at 910° C.	25·3 24·8	35 41	Difficult cold pressings such as wire-wheel hub shells, sumps, clutch housings, tapered disc wheels, etc., thimble tubes for boilers, etc.
N at 900° C. A at 900° C. N at 890° C. A at 890° C.	25·9 25·6 28·8 27·5	36 37 33 34	Automobile parts not highly stressed, seamless hardware, barrows, elevator buckets, gear-cases, ballistic heads for shells, etc.
N at 880° C. A at 880° C. S at 680° C.	31·5 30·0 25·5	28 30 33	Chassis frames, tapered disc wheels, centre-locking hub shells, brake drums, axle and brake housings for automobiles, aircraft parts, etc.
N at 870° C. A at 870° C. S at 680° C.	34·0 32·0 27·5	28 32 35	The most popular steel for cold-pressed brake drums, axle housings, etc., for automobiles.
A at 860° C. S at 680° C.	35·4 29·3	26 32	Brake drums, centre-locking hub shells, and other high-tensile pressings for automobiles.
A at 850° C. S at 680° C.	36·8 30·2	25 30	Higher-tensile brake drums for heavy commercial vehicles, brake drum liners for aircraft, etc.
A at 880° C	38·9	21	High-tensile chassis frames, brake drums, etc., of improved rigidity and/or wearing properties.

[1] N—normalised; A—annealed; S—spheroidized.

The steel is raised to the correct temperature in a suitable furnace. Pressure required depends on quality of steel or other metal, temperature, size of billet, rod, or piece, and number of sections per die.

Mannesmann Tube Process.—In the Mannesmann process, long steel bars are nicked to the desired lengths and mechanically broken at the nicks, thus producing a short steel slug. This is raised to 1250° C. and passed rapidly through a descaling mill comprising a set of rolls. The bars then go to the mechanical extrusion press, which is vertical. The rough ends of the broken bars are first mechanically flattened by pressure, and at the same time pressed into a hollow

receptacle, which they fill, so that a short billet results, which is pierced by a punch or mandrel. The tube thus formed is forced over the punch and through a die. A 40-ft. tube is produced of the diameter desired at this stage. One extremity of the tube comprises a short, solid piece, which is cut off by circular saw. The tube is then brought down to the proper diameter and wall thickness in a set of rolls.

Extruding Chromium-steel Valves.—The steel used contains 0·4–0·5 per cent. carbon, 0·3–0·5 per cent. manganese, 3·0–3·5 per cent. silicon, 8–10 per cent. chromium, 0·025 per cent. sulphur and phosphorus. Bars of this steel are heated to 815° C. and severed by shears into blanks approximately $1\frac{1}{4}$ in. diam. × $\frac{15}{16}$ in. long. Four bars at once are cut. Blanks are tumbled to free them from scale, and reheated in a gas furnace to 1100° C. The hot steel is placed directly into the first die, and the valve stem extruded by a punch. Rectangular slots are then punched in the shank. Fash is cut from the shank end and dirt and scale again removed by tumbling. Finally, the valves are reheated to approximately 700° C. and cut to dead length in a punch press. Dies and punches are of high-speed steel. The valves are thread rolled in threading dies and straightened, being then annealed at 800° C.

Cold Drawing.—Stretching or lengthening unheated metal rods, bars, or coils. It gives a closer control of exact dimensions, a smoother and brighter finish, than other processes. Easier machining is obtained by it, as well as certain physical properties.

Cold Drawing Steel Bars.—Hot-rolled steel bars are pickled in 3–8 per cent. dilute sulphuric acid (or hydrochloric acid) containing a pyridine or other inhibitor. The pickling solution is heated to 65–70° C. After pickling, the bars are washed with water under pressure, then plunged into milk of lime or slaked lime, partly to neutralise the acid and partly to increase the lubrication of the bars during cold drawing. If the lime emulsion is used, it is heated to 80° C. approximately.

By means of a draw bench, the bar is then pulled through a draw plate, i.e. a metal die plate containing tapered holes through which the steel is drawn. Sometimes a gripping appliance on the draw bench pushes the bar end a short distance through the dies, so that the pulling head may seize it and draw it through. Sometimes the bar end is pointed to pass through the die and be similarly gripped. Points may be forged on the bars by swages or " over pickled," i.e. placed vertically in small pickling baths, to the extent of about 6–8 in. The bath is of much stronger concentration than that normally used, and is at first 50 per cent. hot dilute sulphuric acid. This eats away approximately $\frac{1}{8}$ in. of the cross section. This method is only employed if the two previous methods are impracticable.

Lubrication for Cold Drawing.—A box containing grease is placed in front of the die, and is traversed by the bar as it goes forward to the hole in the draw plate. Alternatively, soluble oil is jetted on to the steel as it advances to the die.

Speed of Cold Drawing.—In cold drawing steel, speed ranges from 40 to 100 linear ft. per minute. Special sections and wire have effective cold-drawing speeds between 9 and 600 linear ft. per minute. Four bars are the most that can be drawn at one time. Diameter or width across flats in hexagonal forms is usually reduced by $\frac{1}{16}$ in. or $\frac{1}{32}$ in., but these figures do not represent maxima or minima.

Effect of Bright Drawing on Free-cutting Steel

Composition of Steel: 0·12 per cent. carbon, 0·005 per cent. silicon, 0·234 per cent. sulphur, 0·030 per cent. phosphorus, 0·850 per cent. manganese.

Hot-rolled Bar					*Bright Drawn Bar*				
Y.P.	*M.S.*	*E.*	*R.A.*	*Izod*	*Y.P.*	*M.S.*	*E.*	*R.A.*	*Izod*
16·8 tons per sq. in.	24·8 tons per sq. in.	34% in 2 in.	57%	58 ft.-lb.	26·0 tons per sq. in.	26·8 tons per sq. in.	22% in 2 in.	54%	37 ft.-lb.

Cold-drawn bars need to be straightened mechanically, cut to length and protected against rust by use of a slushing oil.

Wire Drawing.—Rods for wire drawing range from 0·212-in. diam. up to 1 in. Coils of rod approximately 10–300 lb. are employed in Great Britain. An average coil diameter is 30 in. for an average coil weight of 120 lb. Pickling may be in cold hydrochloric or sulphuric acid, but most satisfactory is a solution of ferrous chloride or sulphate and hydrochloric or sulphuric acid. Coils must not be tightly bound. For highest-quality wires where pickling brittleness must be avoided, mechanical banging is employed to supplement pickling as a means of eliminating scale.

The wire is mechanically drawn through a die resembling a truncated cone. Semi-angle of die taper varies from 4 to 12 degrees. As the wire emerges from the die, it is wrapped round a rotating spool or block. In single-holing, the wire is drawn through only one die before being wound. In continuous wire drawing, the wire passes through a series of dies, becoming progressively smaller in diameter as it proceeds, and is wound only when drawing is completed. The ends of the wire are pointed by filing, heating the extremities to soften them, and then drawing them through, or by mechanical pointing rolls.

To take up the increasing length of the wire continuously drawn, separate blocks are interposed on to which the wire is wound before proceeding to the next die. These blocks rotate each at a higher speed than its predecessor.

Wire-drawing Dies.—Chilled cast iron, forged carbon tool steel, chromium steel, tungsten steel, and molybdenum steel, are all used for dies. Chilled cast iron is used for lower grades and thicker sections; 1·6 per cent. carbon steel is used in Great Britain and on the Continent because it is forgeable and can be "battered" and reamered when the holes are worn to restore their original dimensions. Choice of die material is largely governed by type of wire drawn and the market price. Diamond dies are the latest development.

Tungsten-Carbide Wire Dies.–Rough-pierced cylindrical pellets of tungsten-carbide, enclosed in a metal housing, the hole being opened out and finish-ground to size. Advantages are less power consumption (about 30 per cent.) because of lower friction; greater length of service life between resettings; superior wire finish. Disadvantages are greater cost; inability to restore original hole size, holes having to be opened out to next size larger; danger of chipping if carelessly used or if internal stresses are caused by variations in wire temperature.

Standard carbide pellets range from 9 to 32 mm. diam. × 6 to 30 mm. long.

Lubrication for Wire Drawing.—Rods or coils are first coated with iron hydroxide, copper, or tin, applied during or after pickling. Dry soap in bags is the lubricant proper, and the rods pass through this on their way to the die. This is termed dry lubrication. In wet lubrication the wire, after pickling, is immersed in a dilute solution of copper or tin sulphate, or a mixture of both, depending on the colour desired. The coils are then taken out and plunged in a tank of fermented liquor made from rye meal and yeast with water, from which they are removed in the wet condition, the liquor acting as a lubricant. See section on Wire Drawing.

Effect of Cold Drawing on Steel Wire

Composition of Wire: 0·16 per cent. carbon, 0·68 per cent. manganese.

Hot Rolled					*Cold Drawn 13·5% Reduction*				
Y.P.	*T.S.*	*E.*	*R.A.*	*Izod*	*Y.P.*	*T.S.*	*E.*	*R.A.*	*Izod*
20 tons per sq. in.	28·6 tons per sq. in.	38%	70%	96 ft.-lb.	29 tons per sq. in.	34·6 tons per sq. in.	24·5%	60·2%	50 ft.-lb.

Cold Drawn 24·5% Reduction				
Y.P.	*T.S.*	*E.*	*R.A.*	*Izod*
38·1 tons per sq. in.	40·6 tons per sq. in.	13·6%	54·8%	35 ft.-lb.

Cold Drawing Tubes.—The principle is as for bars and wire, but if tube walls are too weak to support the operation, a cylindrical mandrel is inserted as a support. Tube billets are cut into short lengths and pointed at the end by the forging hammer or press, or by swages between revolving hammer dies for smaller billets. Tubes are cut into lengths as they elongate. During pointing, a hole is frequently punched in the pointed end to facilitate entry of pickling solution and lubricant. Pickling is in dilute 5 per cent. sulphuric or hydrochloric acid. Washing, baking in a suitable furnace, and lubrication follow. Baking dries the tube after washing and prevents pickling brittleness. Lubrication is by steeping in palm oil or tallow, or power-pumping oil before drawing.

Three drawing methods are employed: without mandrel, with short fixed mandrel, with long moving mandrel. The first is used when dead accuracy of internal diameter is not needed, where interior finish need not be smooth, and where walls of great thickness are concerned. No internal lubrication is needed. Reduction per draw is 20 to 35 per cent. The second is used for greater internal accuracy, but causes acute friction, and is only recommended for tubes over ½-in. diam. Reduction per draw is 30 to 40 per cent. The mandrel, of special steel, does not go through the die. The third method takes the mandrel through the die, but it must afterwards be withdrawn from the tube mechanically. It is mostly employed for tubes below ½-in. diam., and for medium sizes of greater diameter than ½ in. where the tube walls are thin.

Tube-drawing speed is from 10 to 60 ft. per minute. Tungsten steels are mostly used for dies (3·5 per cent. tungsten). Other materials used are nitrided tool steels and tungsten carbide.

Thread Rolling.—A means of manufacturing threaded parts, e.g. screws, bolts, screw caps, etc., by rolling the threads on to the part under pressure. The parts are made to rotate, and compelled to make contact with rollers to which has been given the desired pitch or form of screw thread. Metal is saved, and the pressure cold works the surface, improving mechanical properties, e.g. toughness. Thread rolling is particularly advantageous for soft metals such as are used in making screw-cap electric-lamp sockets. Aluminium and alpha brass are examples. Thread rolling may be carried out in the lathe, the automatic screw machine, or special thread-rolling machines. In the last-named, approximately 30 to 100 parts a minute may be threaded. Roller size is decided by deducting the single depth of thread from the pitch diameter and multiplying by a factor (usually about 4, but occasionally as high as 12). The arbour and roller are mated by gears, and the roller will possess 1, 2, 3, or 4 threads according to the factor used. There are no specific speeds, each job having its own (see index).

Knurling.—Using a roller or rollers to impress a pattern upon a solid or hollow metal part, the rollers being pressed against the part as it rotates, and themselves carrying the pattern. Knurling may be done on lathe, automatic screw machine, or special knurling machines. Two rollers are usually employed, set apart from each other a distance less than that of the part diameter. Coarse, medium, or fine serrations may be had, by regulating the knurl helix angle. Rollers may be convex or concave if desired. A typical knurling job is the milled edge of an adjusting screw head.

Spinning.—Forming a rotating metal disc on a lathe over a former or chuck by pressing a spinning tool against it. The disc is lubricated with laundry soap or sheep's tallow. A typical spindle speed for mild steel is 300 to 600 r.p.m. Operations include forming by working the tool from centre to circumference and vice versa, and finishing by trimming the rough edges of the spun disc; curling over the edges to make a rim; or beading for ornamental purposes. The deeper the spun part, the thicker the steel will have to be at the beginning, so as to permit the metal to move without thinning the disc centre too much. Intermediate annealings may be necessary where metal becomes work-hardened, and pickling should

follow each annealing to remove scale. Washing and drying precede each new spinning operation.

Formers for spinning are made of beech, birch, or other soft woods for short runs. For long runs, lignum vitæ, cast iron, or steel (chiefly employed for sharp angles or grooves) are used. For long runs on deeply spun work, a range of formers may be used. Sectional formers are often employed for finishing drawn shells. Spinning tools are usually manufactured from high-quality tool steel, but bronze tools are used in spinning steel.

Riveting.—This may be carried out either hot or cold. Cold riveting is essential for smaller rivets and occasionally for very long rivets. High-carbon and high-tensile steel rivets should be cold riveted unless heated electrically. Case-hardened steel rivets may be hot riveted.

Rivet Steel.—Usually a steel of comparatively low carbon content is employed. This has a tensile strength of at least 25 tons per sq. in., with elongation of 30 per cent. in 2 in. Greater strength may call for higher carbon contents. Low-carbon stainless steels are also used for rivets, but must be differently treated. Iron is seldom used except for hand riveting. Steel for rivets should be capable of bending in the cold condition to a curve of internal diameter identical with that of the rivet itself. Hollow rivets are employed only where high strength is not needed.

AVERAGE RATE OF RIVETING ON DRYER SHELLS, TUBE MILL SHELLS, ETC.

Rivet Diameter	*Pneumatic Riveting*	*Hydraulic Riveting*
In.	*Rivets per hour*	*Rivets per hour*
$\frac{3}{8}$	90	—
[illegible]	85	—
[illegible]	70	—
[illegible]	60	50
[illegible]	40	50
[illegible]	35	50
1	30	50
1[illegible]	25	50
1[illegible]	20	50

Hand pneumatic riveting machines use compressed air at 60 to 100-lb. pressure. Approximately 700 blows a minute are struck. Rivets up to $1\frac{3}{8}$-in. diam. may be dealt with. Capacity is 90 to 120 rivets an hour with a stroke up to 9 in.

Hydraulic riveters exert pressures up to 75 tons. Electrical riveting machines exert a pressure of 32 tons per sq. in.

PRESSURES FOR SMALL STEEL RIVETS

Rivet Diameter	*Form of Rivet*	*Amount of Rivet to form Head*	*Tons Pressure*
In.		*In.*	
$\frac{3}{32}$	Round head	$\frac{3}{16}$	1·15
$\frac{1}{8}$	,,	$\frac{7}{32}$	2·25
$\frac{5}{32}$	,,	$\frac{1}{4}$	3·00
$\frac{3}{16}$	,,	$\frac{9}{32}$	4·50
$\frac{3}{32}$	Countersunk	$\frac{7}{32}$	2·25
$\frac{1}{8}$	,,	$\frac{3}{16}$	3·50

Stainless-steel rivets with cone heads should be hot riveted; those with button heads should be cold riveted.

Seasoning Precision Gauges.—To season precision gauges after rough grinding, immerse them in boiling water and ice water alternately approximately thirty times. Hold the gauges in the boiling water and the ice water for a period sufficient to ensure that their temperature equals that of the bath in both instances. There will be a discrepancy of about 180° F. between the two baths. After this treatment, changes in dimensions and form with normal temperature changes will not occur.

Flux for Brazing Steel Tubes.—Borax is not satisfactory, because it froths and may create difficulty because of the high water content of its crystals. Boracic acid should be employed.

Blowpipe Welding Manganese Steel.—Bevel the edges to a 90-degree total vee, by grinding or oxyacetylene blowpipe cutting. If the latter method is employed, grind or pickle the edges to eliminate scale. Preheat large castings in a furnace. Small castings may be preheated with a petrol burner or the welding blowpipe. Carefully support during preheating and welding. Weld in preheating furnace and protect from draughts. Use special manganese steel welding rods. Adjust blowpipe flame to show a slight acetylene excess. Maintain a large pool of welded metal. Do not rub the rod in the weld, but hold under molten pool surface and apply to melt the rod in the molten metal pool. Do not make pool too large. Use relatively large tip or welding heat. Reheat after welding to bright yellow (680° C. approximately), hold for 30 minutes, and quench in tepid water, totally immersing the part.

Steels for Drilling Ceramic Materials.—Cast steel containing approximately 1 per cent. chromium; cast carbon steel with a small chromium content; 14 or 18 per cent. tungsten high-speed steel; extra-hard steel containing tungsten and chromium in the proportions 3 of tungsten to 1 of chromium; tungsten carbide, may all be used.

Cooling Mixture for Carbon Tool-steel Tools.—3¼ lb. borax, dissolved in 22 galls. of boiling water, cooled, and 2 galls. 7 pints lard oil added. This gives better results than lard oil, but it is advisable to grease the machines well before using it.

Modulus of Elasticity.—The number obtained by dividing the stress per unit of cross-sectional area by the increase in unit of length. The area is usually taken in square inches, the stress in pounds, and the increase in length per inch of the bar.

Magnetisation of Steel.—Amount of current required is ascertained from the formula $H = \frac{4\pi}{10} \times \frac{IS}{L}$, where H is the magnetising force, I the current in amperes, S the number of turns of wire on the coil, and L the length of coil.

ALLOTROPIC FORMS OF IRON

Delta Iron	*Gamma Iron*	*Beta Iron*	*Alpha Iron*
Above 1400° C.	1400–900° C.	800–700° C.	Below 700° C.
Octahedral crystal.	Octahedral crystal.	Cubic crystal.	Cubic crystal.
Body-centred.	Face-centred.	Body-centred.	Body-centred.
C.S.L.	C.S.L.		C.S.L.
Not capable of isomorphism.		Capable of isomorphic mixtures.	
Frequent twinning.		Do not twin.	
Austenite.		Beta ferrite.	Alpha-pearlite-ferrite.
Specific gravity high for both.		Medium.	Low.
Electrical conductivity 10 times smaller than alpha.		Greater than gamma.	Greater than beta.
Non-magnetic.		Weakly magnetic.	Strongly magnetic.
Harder than alpha.		Very hard.	Soft.
		Transition stage.	

Jointing of Stainless Steel.—A specially suitable material contains 30 to 70 per cent. manganese, 10 to 60 per cent. copper, 10 to 50 per cent. nickel. By modification of the composition within these limits, the melting-point of the alloy may be varied from 850 to 1060° C. A composition of manganese 40, copper 40, and nickel 10 has proved well adapted for welding rustless steels. The colour of the weld material resembles that of the steel, and the alloy has high chemical resistance. Its properties may be still further modified by adding up to 30 per cent. of chromium, cobalt, iron, aluminium, etc., singly or in combination. A mixture of boric acid and borax makes a satisfactory flux.

Burning Temperature of Steels.—The table shows the temperature at which the different steels listed will burn if forged directly after being heated in a direct-fired gas furnace when employing a considerable excess of gas and a large excess of air.

BURNING TEMPERATURE OF STEELS

Steel Composition Per cent.			*Atmosphere*	*Max. Temp. to which Steel was heated without burning ° C.*	*Min. Temp. at which Steel was found to burn ° C.*
Carbon	*Nickel*	*Chromium*			
0·28	—	—	Excess air	1395	1405
0·28	—	—	Turbulent gas	1440	1470
0·47	—	—	Excess air	1355	1370
0·47	—	—	Turbulent gas	1415	1440
0·93	—	—	Air	1315	1330
0·93	—	—	Gas	1315	1330
1·19	—	—	Air	1270	1290
1·19	—	—	Gas	1270	1290
0·24	3·48	0·05	Air	1410	1420
0·24	3·48	0·05	Gas	1425	1440
0·43	1·20	0·39	Air	1370	1385
0·43	1·20	0·39	Gas	1410	1420
0·52	2·05	0·83	Air	1370	1390
0·52	2·05	0·83	Gas	1385	1400

TYPICAL TENSILE PROPERTIES OF CHROMIUM MOLYBDENUM STEEL OIL-QUENCHED (870° C.) AND TEMPERED

Yield-point lb. per sq. in.	*Ultimate Tensile Strength lb. per sq. in.*	*Elongation in 2 in. Per cent.*
115,000	130,000	11·0
140,000	155,000	9·0
160,000	180,000	10·0
185,000	215,000	8·0

Soft Soldering Stainless Steel.—Clean in 50 per cent. hydrochloric acid. Rinse in clear water and dry. To flux, dissolve zinc in a warm 50 per cent. solution of hydrochloric acid, adding as much zinc as will dissolve. Alternative flux is zinc chloride mixed with 50 per cent. hydrochloric acid to form a creamy paste. Apply flux liberally, completely covering surfaces to be soldered. Wash in warm water after soldering.

Relation between Hardness and Tensile Strength of Medium Carbon Steel and Cutting Speed

Tensile Strength Tons per sq. in.	*Brinell No.*	*Speed Factor*
25	120	1·54
30	140	1·28
34	160	1·00
38	176	0·83
44	200	0·67
48	220	0·57
53	240	0·51

Power Consumption when Cutting Medium Carbon Steel and Cast Iron

	Steel	*Cast Iron*
Brinell No.	176	156
Tensile strength, tons per sq. in.	37·5	33·4
Cutting angle of tool	70°	75°
Plan angle of tool	60°	60°
Clearance angles	6°	6°
Nose radius	$\frac{3}{8}$ in.	$\frac{1}{8}$ in.

Medium Carbon Steel Cut at 100 ft. per Minute. No Coolant used. Net h.p. consumed.

Depth of Cut in In.	*Traverse in In.*			
	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$
$\frac{1}{32}$	0·8	1·4	3·1	4·2
$\frac{1}{16}$	1·6	2·8	6·1	8·4
$\frac{1}{8}$	3·1	5·6	12·2	16·8
$\frac{3}{16}$	4·7	8·5	18·3	25·3
$\frac{1}{4}$	6·2	11·3	24·4	33·7
$\frac{5}{16}$	7·8	14·1	30·5	42·0
[illegible]	9·4	16·9	36·5	50·5
[illegible]	12·4	22·5	48·8	67·3

Cast Iron Cut at 50 ft. per Minute. No Coolant used. Net h.p. consumed.

Depth of Cut in In.	*Traverse in In.*			
	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$
$\frac{1}{32}$	0·17	0·36	0·69	1·15
$\frac{1}{16}$	0·32	0·62	1·17	1·97
$\frac{1}{8}$	0·67	1·15	2·12	3·61
$\frac{5}{16}$	1·01	1·70	3·07	5·25
$\frac{1}{4}$	1·35	2·20	4·02	6·88
$\frac{5}{16}$	1·69	2·72	4·97	8·53
[illegible]	2·02	3·25	5·92	10·15
[illegible]	2·70	4·30	7·82	13·43

Relation between Temperature and Tensile Strength of Iron and Steel. Lb. per sq. in. at Varying Temperatures

Temperature ° C.	*Wrought Iron*	*0·3 Carbon Steel*	*0·5 Carbon Steel*	*0·75 Carbon Steel*	*1·0 Carbon Steel*
1205	2,250	—	—	—	—
1150	3,500	4,000	—	—	—
1095	4,500	5,000	5,600	6,500	—
1040	5,100	5,800	7,300	8,800	13,000
980	5,800	6,700	8,800	11,000	17,000
925	7,000	8,600	10,700	13,800	23,000
870	8,600	10,000	12,500	15,600	31,000
760	12,600	14,000	151,500	17,000	—
650	18,000	—	—	—	—
540	25,600	—	—	—	—
(cold) 15	50,000	70,000	85,000	100,000	120,000

Energy Required to Remove 1 cu. in. of Metal. Values in 1000 in.-lb.

Material	*Brinell No.*	*Feed per Rev. in In.*				
		0·0025	0·005	0·010	0·020	0·040
Armco iron	89	714	536	402	—	—
Wrought iron	93	—	—	—	—	—
Machinery steel	109	672	497	405	367	—
Malleable iron	112	315	244	221	191	202
High-carbon iron	113	256	215	193	173	—
Hard malleable iron	118	315	244	201	179	177
Annealed cast steel	131	607	432	374	—	—
Grey iron	143	298	237	206	170	—
Cold-rolled steel	191	—	—	394	350	—
Annealed silver steel	237	—	—	—	—	—

Hardness Table for Well-boring Drill Bits

Temperature ° C.	*Brinell No. Oil-quenched*	*Brinell No. Water-quenched*
680	187	187
710	187	187
740	187	187
770	187	187
780	187	187
800	302	444
830	321	512
850	375	512
880	418	—
900	444	—
950	512	—

Quenching Temperature Recommended: 900–950° C. in oil

Plating Stainless Steel.—For plating these steels with silver, copper, or nickel, as may on occasion be required, the normal plating solutions are unsuitable. Use 25 per cent. solution of sulphuric acid, employing a lead rod anode and the stainless steel as the cathode. Voltage 4 to 6 volts. Temperature of solution held at 20 to 27° C. Alternatively, use 30 per cent. hydrochloric acid solution, using a carbon anode with voltage as above, holding bath temperature at 60° C. Carefully clean before and rinse in alkali and wash after plating.

NON-FERROUS METALS

Specific Gravities of Non-ferrous Metals

Aluminium	2·68	Magnesium	1·75
Brass	8·4	Nickel	8·9
Bronze	8·6	Tin	7·3
Copper	8·8	Zinc	7·2
Lead	11·3		

Aluminium.—A white metal, high in tensile strength, malleabilty, and conductivity. Atomic weight, 26·97; atomic number, 13; melting-point, 6587° C. Specific gravity, 2·68 approx. Light in weight, low in density.

In cast condition, tensile strength 6 to 7 tons per sq. in. Elongation about 3·0 per cent. in 2 in. Electrical conductivity about 61 per cent. that of copper. Obtainable in 99·8 per cent. pure condition. Density, 2·6989 g. per c.c. at 20° C. in the cold-rolled condition, and 2·6996 g. per c.c. in the annealed condition. Thermal expansivity given by the equation $L_t = L_0\,(1 + (23{\cdot}22t - 0{\cdot}00467t^2 - 0{\cdot}0000078t^3)10^{-6}$ for the temperature range 20 to 500° C. Here, L_0 is original length, and L_t is length at temperature t.

Thermal conductivity: about 0·55 c.g.s. units at normal temperatures. Has been alloyed with chromium, copper, iron, magnesium, manganese, nickel, silicon, titanium, magnesium-silicon, magnesium-zinc, magnesium-chromium, copper-iron-magnesium, copper-magnesium-manganese, copper-magnesium, copper-nickel-magnesium, magnesium-manganese, silicon-copper-magnesium, and silicon-nickel-copper-magnesium.

Principal alloys: (*a*) those with copper; (*b*) those with copper and magnesium; (*c*) those with copper and zinc; (*d*) those with silicon; (*e*) those with silicon and copper.

MECHANICAL PROPERTIES OF COPPER-ALUMINIUM ALLOYS

Alloy	*Sp. Grav.*	*Y.P. tons per sq. in.*	*M.S. tons per sq. in.*	*Elong. %*	*Brin. No.*	*Izod ft.-lb.*
4L 11 (6–8 per cent. copper) as cast	2·8–2·93	4–8	10–12	3–6	54–64	2–5
3L 8 (11–13 per cent. copper) as cast	2·9–2·95	6–7	11–14	1·5–2·5	74–87	1·0–2·5
6 per cent. copper alloy (heat-treated, i.e. quenched and aged)	2·82	9·5	21	13	95	8

Duralumin.—Contains 3·5–4·5 per cent. copper, 0·4–0·7 per cent. manganese, 0·4–0·7 per cent. magnesium, approximately 0·4 per cent. silicon, and iron not more than 0·5 per cent. Specific gravity, 2·74–2·79. Density, 0·099–0·101 lb. per cu. in. As cast, maximum stress 10–12 tons per sq. in. Air-cooled: yield point, 7 tons; maximum stress, 18 tons per sq. in.; elongation, 21 per cent. in 2 in.; reduction of area, 44 per cent.; Brinell No. 65. Water-quenched: yield-point, 7 tons; maximum stress, 17 tons; elongation, 20 per cent.; reduction of area, 41 per cent.; Brinell No. 63. Quenched and aged: yield-point, 15 tons; maximum stress, 26 tons; elongation, 20 per cent.; reduction of area, 35 per cent.; Brinell No. 98.

Coefficient of linear expansion about 0·000023 per 1° C. Thermal conductivity about 0·3 c.g.s. units.

Y Alloys.—Contain 4 per cent. copper, 2 per cent. nickel, 1·5 per cent. magnesium, with a little iron and silicon as impurities. Stronger than duralumin at high temperatures.

PHYSICAL PROPERTIES OF Y ALLOYS

	Cast	*Cast and Heat-treated*	*Hot-worked and Heat-treated*
Ultimate tensile strength, tons per sq. in.	12–14	18–22	22
1 per cent. proof stress, tons per sq. in.	10–11	14–16	14
Elongation per cent. in 2 in.	2	4–6	15
Brinell No.	82–85	96–105	105
Izod impact, ft.-lb.	1	3–5	—
Specific gravity	2·79	2·78	2·79

Thermal conductivity at 25° C.: 0·31–0·32 c.g.s. units. Coefficient of thermal expansion per ° F., approximately 0·0000125. Modulus of elasticity, 10,300,000 lb. per sq. in. approximately.

RR. Alloys.—Contain small percentage of nickel. Superior to other aluminium alloys for high temperatures.

COMPOSITIONS

Type	*Cu*	*Ni*	*Mg*	*Fe*	*Ti*	*Si*	*Used in form of*
RR.50	1·3	1·3	0·1	1·0	0·18	2·2	Castings
RR.53	2·25	1·3	1·6	1·4	0·1	1·25	Die and sand castings
RR.56	2·0	1·3	0·8	1·4	0·1	0·7	Forgings, etc.
RR.59	2·25	1·3	1·6	1·4	0·1	0·5	Forgings, etc.

Average physical properties: specific gravity, 2·7–2·75; thermal conductivity, 0·40 c.g.s. units; coefficient of linear expansion, 0·000022 per ° C.

MECHANICAL PROPERTIES OF RR. ALLOYS

Type	*1% Proof Stress tons per sq. in.*	*Ultimate Tensile Stress tons per sq. in.*	*E. %*	*R.A. %*	*Brinell No.*	*Condition*
RR.50	9–11	11–13	2–4	12	65–75	Cast
RR.50	11–13	13–16	4–6	10	70–80	Heat-treated
RR.53	18–20	18–20	·5–1·0	4	124–148	Cast
RR.53	21–23	21–23	1	·5–1·5	124–148	Heat-treated
RR.56	21–23	27–30	10–15	14–25	121–138	,,
RR.59	20–22	27–30	10–15	17·8	121–148	,,

Silicon-aluminium Alloy DTD.25.—10–14 per cent. silicon; 0·5 per cent. manganese (maximum); 0·75 per cent. iron (maximum); balance, aluminium. Coefficient of expansion, 0·0000111 per ° F. Yield-point, 10–12 tons. Maximum stress, 12–14 tons per sq. in. Elongation, 7–8 per cent. in 2 in. Density, 2·6–2·7. Brinell No. 45–60 as cast, 65–80 die cast. Rockwell No. E.48–E.72. Modulus of elasticity, 10,300,000 lb. per sq. in. Weight per cubic inch approximately, 0·096 lb. Thermal conductivity at 25° C., 0·33–0·36 c.g.s. units.

Magnesium-aluminium Alloys

Electron Metal. Cast Alloys

Type	*Al*	*Zn*	*Mn*	*Mg*	*Impurities*	*Cu*	*Si*
DTD.136A	9–11	3·5 (max.)	0·5 (max.)	Balance	1·5 (max.)	—	—
DTD.281 .	9–11	1·0 (max.)	0·5 (max.)	Balance	1·0 (max.)	—	—
DTD.285 .	9–11	1·0 (max.)	0·5 (max.)	Balance	1·0 (max.)	—	—
DTD.59A	8·5 (max.)	3·5 (max.)	0·5 (max.)	Balance	1·7 (max.)	—	—
DTD.289 .	8·5 (max.)	3·5 (max.)	0·5 (max.)	Balance	1·0 (max.)	—	—
DTD.140A	0·2 (max.)	2·5 (max.)	0·2 (max.)	Balance	0·5	0·2	0·4

Mechanical Properties of Electron Alloys, Cast and Wrought

Type	*Condition*	*Ult. Tens. tons per sq. in.*	*Elong. % on 2 in.*	*Proof Stress*	*Brinell No.*
DTD.136A .	Cast .	8·5–10·5	1–3	4·5–5·5	55–65
DTD.281 .	Heat-treated	14–17	6–10	5·0–6·5	50–60
DTD.285 .	Heat-treated	13–14	1–2	6·5–7	65–75
DTD.59A .	Cast .	9–14	2–8	4–4·5	45–50
DTD.289 .	Heat-treated	13–15	6–10	4–4·5	45–55
DTD.140A .	Cast .	6–7	3–4	1·5	30–35
DTD.259 .	Extruded	18–22	$\frac{16\text{–}12}{4\sqrt{a}\%}$	9–12	55–60
DTD.88B .	Forged .	15 min.	5 min.	8 min.	65–70
DTD.142 .	Extruded	15 min.	2 min.	8 min.	40–50.
DTD.118 .	Rolled .	12–15	10–3	6–8	—
DTD.120A .	Rolled .	16 min.	10 min.	7 min.	—

Electron Metal. Wrought Alloys

Type	*Al*	*Zn*	*Mn*	*Mg*	*Impurities*	*Cu*	*Si*
						(Max.)	(Max.)
DTD.259	11·0 (max.)	1·5 (max.)	1·0 (max.)	Balance	1·5 (max.)	—	—
DTD.88B	11·0 (max.)	1·5 (max.)	1·0 (max.)	Balance	1·5 (max.)	—	—
DTD.142	0·2 (max.)	0·2 (max.)	2·5 (max.)	Balance	0·5 (max.)	0·2	0·4
DTD.118	0·2 (max.)	0·2 (max.)	2·5 (max.)	Balance	0·5 (max.)	0·2	0·4
DTD.120A	9·0 (max.)	1·5 (max.)	1·0 (max.)	Balance	—	0·3	0·4

Heat Treatment of Aluminium and its Alloys.—Fully soften immediately after cold working by heating to a temperature between 340 and 355° C. Some alloys may need as high a temperature as 400° C., though the same effect may be had by prolonging the heating period at lower temperatures. Heat should not be maintained longer than 1 hour. Normal annealing temperature is 340° C. Slow cooling is advantageous.

For maximum softness and ductility, maintain at 218° C. annealing temperature for a minimum period of 1 hour, cool slowly in the furnace at a cooling rate of 10–15° C. per hour, and when temperature has fallen to 270° C. take out of furnace and cool in air.

For solution heat treatment, use a fused sodium nitrate salt bath. Rivets and small parts may be heated in molten nitrate or lead. Insert parts in a cylindrical

steel container with sealed base and covered top. Immerse in bath deep enough for level of fused liquid salt to rise nearly to top of container.

SOLUTION TREATMENT TEMPERATURES FOR ALUMINIUM ALLOYS

Type	° *C.*	*Type*	° *C.*	*Type*	° *C.*
5L3	485–505	6L.1	485–505	5T.4	485–505
2L38	485–505	2L.39	485–505	DTD.273	480–500
DTD.356	505–515	2L.40	505–515	DTD.450	520–530
L.47	505–515	L.45	505–515	DTD.460	520–530
DTD.390	480–500	DTD.364A	505–515	4L.25	490–525
DTD.270	480–500	DTD.443	520–530	DTD.147	470–490
DTD.275	480–500	DTD.423A	520–530	DTD.150A	484–505
				DTD.324	520–535
				DTD.327	480–500
				2L.37	485–505

PRECIPITATION TREATMENT TEMPERATURES FOR ALUMINIUM ALLOYS

Type	° *C.*	*Type*	° *C.*	*Type*	° *C.*
2L.40	165–175	L.45	165–175	DTD.356	155–175
L.47	165–175	DTD.364A	155–175	DTD.324	130–160
DTD.423A	165–175	DTD.460	165–175		

Period of temperature maintenance: 10 to 20 hours except for: DTD.364A (a minimum of 10 hours); DTD.324 (a minimum of 5 hours); and DTD.423A and 460 (5 to 10 hours).

Hot and Cold Working of Aluminium and its Alloys.—Hot work at 150–205° C. The latter is the best temperature, so long as it is not maintained more than half an hour. Cold working can only be carried out within 1 to 2 hours of the solution treatment. For complex work the limit should be 1 hour. (These restrictions do not apply to alloys given a refrigeration treatment.) Solution-treated sheet may be cold formed without special annealing, but for deep drawing, heat in a forced-air circulation furnace at 340–420° C. and slow cool. Avoid excessive reheatings.

BENDING RADII FOR ALLOYS 5L.3, L.38, DTD.275, AND DTD.390

Sheet thickness:	18 s.w.g. and thinner		Over 18 s.w.g.	
Angle of bend:	Less than 120°	More than 120°	Less than 120°	More than 120°
Condition of Material	*Minimum Bend Radii*			
Annealed	½T	1T	½T	1T
One hour solution-treated .	½T	1½T	1½T	2T
Heat-treated and aged . .	2T	3T	2½T	3T

If fractures are met with in cold forming, warm the metal to 100–180° C. in a hot oil or salt bath, but avoid direct flame heating or other uncontrolled heating methods. Cold punching or pressing these alloys should be done with steel tools, hardened and polished. Bronze tools may be used for short runs and simple jobs. They are easy to cast accurately to form. Zinc dies are only suitable for simple work. Some special jobs demand wood or rubber tools. Consult the alloy makers on these points.

Copper and its Alloys.—Obtainable in 99·95 per cent. purity. This is termed "high-conductivity" copper, and is used for electrical machine windings, busbars, switchgear parts, battery connections, cables for power transmission, etc. "Best select" copper has been refined, but contains small impurity contents. Suitable where maximum electrical conductivity is not required. "Tough-pitch" copper contains 0·3–0·5 per cent. arsenic to give higher strength and toughness, with lower electrical and thermal conductivity. Suitable for locomotive fireboxes, rivets, staybolts, etc. "Cathode" copper has been electrolytically refined. Is used mainly for making alloys, and is normally obtained in plates up to 3 ft. sq. × ¾–⅞ in. thick, weighing as much as 240 lb. "Deoxidised" copper is obtained by using deoxidisers such as phosphorus, silicon, lithium, magnesium, beryllium, and calcium.

Properties of Copper.—Cast: tensile strength, 10–11 tons per sq. in. Cold worked and annealed: tensile strength, about 14 tons per sq. in.; elongation, 45 per cent. in 2 in. Cold drawn: tensile strength, 20–32 tons per sq. in., elongation up to 5 per cent. in 2 in. Annealed copper has a specific resistance of about 1·59 microhms per cu. cm. Coefficient of resistance is below 0·0006 per ° C.

RELATIVE ELECTRICAL AND THERMAL CONDUCTIVITIES AND THERMAL EXPANSION OF COMMERCIALLY PURE METALS AT 20° C.

Material	*Rel. Elect. Cond. Copper = 100*	*Rel. Therm. Cond. Copper = 100*	*Coeff. of Lin. Expansion ° C. at 20° C. × 10^{-6}*
Aluminium	62	56	23
Antimony	4·5	5	11
Cadmium	23	24	31
Cobalt	18	17	12
COPPER	100	100	16·6
Gold	72	76	14
Iron	17	17	12
Lead	8	9	28
Magnesium	39	41	26
Nickel	25	15	13
Platinum	16	18	9
Silver	106	108	19
Steel	13–17	13–17	12
Tin	15	17	21
Zinc	29	29	30

Thermal conductivity, 0·941 cal. per sq. cm. per cm. per sec. per ° C. at 20° C. (high-conductivity copper); 0·92 c.g.s. units or 0·74 B.Th.U. per sq. ft. per in. per sec. per ° F. for commercially pure copper. Specific heat at room temperatures: 0·092 cal. per gramme per ° C., increasing with temperature to 0·098 cal. per gramme per ° C. at 300° C.

LINEAR COEFFICIENTS OF EXPANSION VALUES FOR VARIOUS TEMPERATURES (MOCHEL)

Temp. Range	*Coefficient of Expansion of Copper*	
° C.	*° C.*	*° F.*
20–100	0·0000166 ($16{\cdot}6 \times 10^{-6}$)	0·00000922 ($9{\cdot}22 \times 10^{-6}$)
20–300	0·0000176 ($17{\cdot}6 \times 10^{-6}$)	0·00000978 ($9{\cdot}78 \times 10^{-6}$)
20–500	0·0000186 ($18{\cdot}6 \times 10^{-6}$)	0·00001033 ($10{\cdot}33 \times 10^{-6}$)

Melting-point of pure copper, 1083° C. Specific gravity, 8·94. Cast copper weighs about 0·31 lb. per cu. in.

The Brasses.—Includes the "gilding metals," containing 80–95 per cent. copper and the balance zinc; and alloys with 55–80 per cent. copper and the balance zinc. "Basis quality" brass has approximately 63 per cent. copper. "Cartridge" brass has approximately 70 per cent. copper. "Muntz metal" contains approximately 60 per cent. copper.

REPRESENTATIVE BRASSES WITH TYPICAL MECHANICAL PROPERTIES

Material	*Condition*	*Y.P.*	*M.S.*	*Elong.*	*Brinell No.*
		Tons per sq. in.	*Tons per sq. in.*	*Per cent.*	
High-quality 70/30 Brass	Chill cast ..	5·5–6·0	15·0–16·0	55·0	60
High-quality 70/30 Brass	Hard drawn .	17·0–22·0	28·0–38·0	5·0	150–200
High-quality 70/30 Brass	Hard drawn and annealed	6·0	19·0–22·0	60–65	60
Muntz metal .	Cast . .	—	22·0–25·0	30 on 4 in.	89–100
60/40 brass . .	Hot-worked and annealed	11·5	25·0	4050	96–100

Average thermal coefficients of expansion per ° C.: 0·000018 (18×10^{-6}) for gilding metal (80/20); 0·000019 (19×10^{-6}) for 65/32 brass; and 0·000020 (20×10^{-6}) for Muntz metal. Specific heat at normal temperatures averages 0·092 gramme-cal. per gramme. Average density: 531–534 lb. per cu. ft., i.e. 0·307–0·309 lb. per cu. in. Specific gravity averages 8·28 for 50/50 brass, and varies proportionately with copper percentage.

Leaded Brass—Contains 59·2 per cent. copper, 29·0 per cent. zinc, 1·7 per cent. lead. Mechanical properties: yield-point 7·5 tons per sq. in.; maximum stress, 18·0 tons per sq. in.; elongation, 18 per cent. in 2 in.

Admiralty Brass.—Contains a maximum of 1 per cent. tin with about 70 per cent. copper, 29 per cent. zinc. Used for condenser tubes on marine craft. To ensure maximum ductility, must be annealed before cold working. After cold working, yields about 40 tons per sq. in. tensile strength, and elongation about 10 per cent. in 2 in.

Naval Brass.—Contains at least 57·5–59·5 per cent. copper, 0·6–1·0 per cent. tin, 0·75 per cent. (maximum) impurities, the balance being zinc. Used in cast form for underwater fittings of marine craft. Has a tensile strength of 26 tons per sq. in. (minimum). Elongation, 20–35 per cent. in 2 in.

Manganese Bronze.—Contains about 1 per cent. manganese, 60 per cent. copper, 40 per cent. zinc, with a small iron content and minor percentages of tin, lead, or aluminium, such additions not exceeding a total of 5 per cent. Tensile strength, 28–33 tons per sq. in. as cast; elongation, 30–40 per cent. Used for propellers, rudders, etc., of marine craft.

Aluminium Brass.—Contains 75 per cent. copper, 22 per cent. zinc, approximately 2·0 per cent. aluminium. Tensile strength, 40 tons per sq. in. in the hard-drawn condition. Elongation, 10 per cent. in 2 in. Proof stress, 28 tons per sq. in. In the extruded condition: tensile strength 22 tons per sq. in; elongation, 70 per cent. in 2 in; proof stress, 6 per cent. Used for corrosion-resisting purposes.

THE BRONZES

Material	Composition (per cent.)								
	Cu	Tin	P	Al	Pb	Be	Ni	Zn	Si
Phosphor-bronze	94·9	5–20	0·1–1·0	—	0–20	—	—	—	—
Gunmetal	89	5–20	—	—	0–20	—	—	2–6	—
Aluminium bronze	90	—	—	10	—	—	—	—	—
Silicon bronze	96	—	—	—	—	—	—	—	4
Beryllium copper	97·5	—	—	—	—	2·5	—	—	—
Bearing bronze	70	—	—	—	30	—	—	—	—
Bearing bronze	94–86	—	—	—	—	5–20	—	—	1–2

Aluminium Bronze.—Extensively used for die casting. Electrical and thermal conductivities are between 12 and 17 per cent. of that of high-conductivity copper. Linear coefficient of thermal expansion per ° C. (10 per cent. Al) is about 17×10^{-6} within a temperature range of 20–100° C. Above these temperatures value increases appreciably until over a range of 20–250° C. it averages about 18×10^{-6}. Elastic modulus: approximately $17{\cdot}5$–19×10^{-6} lb. per sq. in. Used for corrosion resistance, heat resistance, and decorative appearance. Harder types (13 per cent. Al) used for forming dies and drawing dies for strip and sheet, but not for deep drawing. Also for non-sparking tools.

MECHANICAL PROPERTIES OF BRONZES

Material	Tensile Strength	El. Lim.	Y.P.	E.	Izod Impact	Brinell No.
	Tons per sq. in.	Per sq. in.	Per sq. in.	Per cent.	ft.-lb.	
88 copper, 10 tin, 2 zinc; 88 copper, 8 tin, 4 zinc	13·5–20	5–8	8–10	15–40	7–14	60–80

Specific gravity, 8·5–8·8; weight per cu. in., 0·314; electrical resistivity, approximately 15·5 for alloy 1 and 13·5 for alloy 2 in table above.

Heat Treatment of Copper and Copper Alloys.—To anneal fully high-conductivity copper, heat to 200° C. or give prolonged heating at 120° C. For commercial copper, anneal at 500° C., or 600° C. for massive sections. Small sections and wire: anneal at 300° C. (maximum) in controlled atmosphere. Cool down slowly or water quench. Water quenching is quicker and gives a rather softer copper.

Anneal the brasses at an average temperature of 600–650° C. according to composition. Water quench only if desired to save time. Relieving of stresses to prevent seasonal cracking requires heating to 250–270° C. for 30–60 minutes and allowing to cool.

Bronzes are slightly improved by annealing, but the treatment has limitations. Average annealing temperature, 550–760° C. according to composition. Gunmetal should be annealed at about 700° C. for half an hour. Aluminium bronze should be annealed at approximately 600° C.

Copper-beryllium alloys should be annealed after cold working. In general, annealing range lies between 400 and 705° C., but in practice, the normal range is 600–700° C.

Hot and Cold Working of Copper and Copper Alloys.—Hot working should be carried out at a temperature between 800 and 900° C. Higher temperatures

up to 1000° C. may be used in special circumstances, but 1000° C. must not be exceeded, or the metal may be burned. Tough-pitch copper should never be heated in a reducing atmosphere.

Cold working produces a hardening effect on copper. Periodical annealing between operations is desirable.

Brasses may be hot worked between 600and 800° C. The lower the percentage of copper the easier the operations. Brasses with over 70 per cent. copper must be worked at somewhat higher temperatures. Cold working improves hardness and mechanical strength, but not ductility, of the brasses.

Not all the bronzes are capable of being hot and cold worked. Hot work is, actually, seldom carried out on them. Aluminium bronze may be hot rolled at temperatures between 850 and 900° C. so long as the aluminium content does not exceed 7–8·5 per cent. Alpha and duplex aluminium bronzes demand hot-working temperatures of 850–900 down to 750° C. for heavy sections of the duplex bronze. Below 750° C. metal should be reheated for further working. Cold working of the duplex aluminium bronzes is not recommended, but the alpha bronze may be rolled, drawn, made into tubes, bent, formed, pressed, etc.

Bronzes with 6 per cent. tin or over should not be cold worked. Alpha-beta bronzes for bearings should not be cold worked, but may be worked if heated to temperatures over 510° C. and quenched in water. Beryllium copper is readily cold or hot worked after annealing. Copper-silicon alloy may be readily hot worked commercially within the temperature range 650–800° C.; 800° C. must not be exceeded or hot brittleness will result. The alloy may also be cold worked.

Nickel Alloys

Monel Metal.—Range of composition: Nickel, 65–70 per cent.; copper, 26–30 per cent.; iron, up to 3 per cent.; manganese, up to 1·5 per cent.; silicon, up to 0·25 per cent.; carbon, up to 0·25 per cent. Castings may have up to 4·0 per cent. silicon.

Density, 8·80; weight, 0·318 lb. per cu. in.; melting-point, 1350° C. Specific heat (20–400° C.), 0·127; coefficient of expansion (25–100° C.), 0·000014; per 1° C. (25–300° C.), 0·000015. Heat conductivity (0–100° C.), one-sixth that of commercial copper; electrical resistivity (at 0° C.), 42·5 microhms; ohm-mil.-ft., 256.

Monel is highly resistant to corrosion and is variably magnetic. It is not hardenable by heat treatment, but may be improved in mechanical properties by cold work. Modulus of elasticity, 25–26,000,000 lb. per sq. in.

MECHANICAL PROPERTIES OF MONEL METAL

Condition	*Ultimate Strength*	*Yield-point*	*Elongation on* $4\sqrt{area}$	*Hardness*
	Tons per sq. in.		%	
Normal (hot rolled)	34–38	15–18	35	Brinell 120–140
Hard (cold drawn)	40–45	35–40	18–20	Brinell 190–210
Annealed (cold rolled)	30–35	14–17	35	Brinell 110–120
Wire (cold drawn)	55–60	50–55	5–10	—
Wire, annealed (cold drawn)	29–33	14–16	35	—
Cast, normal	19–23	12–15	12	Brinell 110–130

Monel metal is superior to brass or bronze in retention of strength at high temperatures. Torsional strength in the hot-rolled condition is 27–28 tons per sq. in.; breaking strength, 12–16 tons yield-point; and limit of proportionality, 9–13 tons. In the cold-drawn condition, the corresponding figures are 40–42 tons, 33–36 tons, and 20–22 tons.

STRENGTH OF HOT-ROLLED MONEL METAL AT HIGH TEMPERATURES

Temperature, ° C.	*Ultimate Tensile Strength, tons per sq. in.*	*Limiting Creep Stress, tons per sq. in.*	*Limit of Proportionality tons per sq. in.*
Room	37	—	15
100	35	—	14
200	33	—	13
300	34	—	12
400	32	22	10
500	28	10	6
600	20	2	—
700	14	1	—

Hot Working of Monel Metal.—The material may be hot worked within the temperature range 1040–1150° C. If extreme caution is employed, the range may be widened to 1180° C. Monel ceases to be malleable at approximately 1210° C. Do not forge at temperatures below 650–870° C., and only in exceptional circumstances between 870 and 1040° C.

Annealing of Monel Metal.—Box anneal small pressed parts, rivets, coiled wire, etc. Open anneal in oven or reverberatory type of furnace such parts as cupped and drawn shapes, spinnings, rods, tubings, etc. Anneal at 730–790° C. for approximately 1 hour at temperature. Total time in furnace is governed by heating rate. Open-annealing range is 950° C. for 3 minutes at temperature, where mechanical working is to follow.

To Reduce Oxidation after Annealing of Monel.—Quench in 1 gall. methyl or denatured ethyl alcohol to 50 galls. water. A pink colour from this quench indicates furnace oxidation and wrong heating conditions, or too much delay in quenching.

Pickling Monel Metal.—After annealing, pickle in 40 galls. water, 6 lb. sodium nitrate, 3 lb. sodium chloride, and 1 gall. 66°Be sulphuric acid. Maintain bath temperature at 80–95 °C. Solution should be kept in brick-lined or ceramic tank. Wood is useless.

If this solution fails to remove obstinate scale, use hydrochloric acid in the proportion 1 part by volume commercial acid to 2 parts water. Remove parts frequently, and scrub with pumice, fine sand, etc.

Tarnish may be removed by adding 0·1 gall. 66°Be sulphuric acid and 1·1 lb. sodium dichromate to 1 gall. water. Pickling period varies from 20–90 minutes, according to scale thickness.

Bright Dipping of Monel Metal.—Use 1 gall. water, 1·5 galls. 66°Be sulphuric acid, 2·2 galls. 38°Be nitric acid. Cool and add 0·2 lb. sodium chloride. Time required: 30 seconds to 2 minutes.

Further Monel Facts.—Monel metal may be machined, and for automatic-screw machine work a free-machining quality is obtainable. Welding is feasible by either gas or electric methods. Flux for gas-welding with borax-boric acid. For electric welding, use a special deoxidising flux. The metal may be soft-soldered with high or low tin solder. Lead fillets are sometimes employed in special instances, and brazing and silver solders are employed for corrosion-resistant joints.

Monel is cast at high temperatures (approximately 1540° C.), special technique being required. Magnesium is employed for deoxidation. Contraction allowance is ¼ in. per foot.

Malleable Nickel.—Similar to Monel metal, but higher in first cost, and contains no copper. Density, 8·85; melting-point, 1450° C. Weight, 0·319 lb. per cu. in. Specific heat (20–400° C.), 0·130. Thermal expansion (25–100° C.), 0·000013; (25–300 °C.), 0·0000145. Heat conductivity (0–100° C.), 0·014 c.g.s. units. Electrical resistivity (at 0° C.), 10·9 micro-cm.^{3}. Coefficient of electrical resistivity per ° C., 0·0041.

MECHANICAL PROPERTIES OF MALLEABLE NICKEL

Condition	*Prop. Limit*	*Y.P.*	*Ult. Strength*	*E. %*	*R.A. %*	*Endurance Limit tons per sq. in.*	*Brinell No.*	*Rockwell B. No.*
	Tons per sq. in.							
Rolled and annealed	7·5–10·3	9–13	29–33	43–53	65–75	11–14	75–95	50–60
Cold or hard rolled	up to 33	up to 45	up to 63	—	—	17–19	up to 150	up to 100
Cast . .	—	9–13	27–31	15–35	30–50	—	80–125	50–60

Malleable nickel is forgeable, can be machined, spun, polished, and pickled. Contraction allowance for casting is $\frac{1}{4}$ in. per foot. It is highly corrosion-resistant, and may be welded by gas or electrical processes. For gas welding, flux with ordinary boric acid, not borax. The material may also be soft soldered, silver soldered, or brazed, employing the same technique as for copper. Anneal between 600 and 900° C. Forging and rolling temperature range is 850–1250° C. Pickling solution: mixture of sulphuric acid, sodium nitrate and salt, hot, and agitated. Time required: approximately 15 minutes.

Inconel.—A nickel alloy highly heat and corrosion resistant, with good mechanical properties. Composition: nickel, 80 per cent.; chromium, 12–14 per cent.; balance, iron. Density, 8·55. Weight, 0·309 lb. per cu. in.

MECHANICAL PROPERTIES OF INCONEL

Condition	*Tensile Strength*	*Yield-Point*	*Elongation % on 2 in.*
	Tons per sq. in.		
Annealed sheet and strip	35–40	15–20	55–35
Annealed rod . .	35–40	15–20	55–35
Hard-drawn rod .	40–60	20–48	30–20
Wire, annealed . .	35–40	15–20	55–45
Wire, spring temper .	85–88	—	—

Coefficient of expansion (40–100° C.), 0·0000115 per °C.; (40–700° C.), 0·0000161 per °C. Heat conductivity, 3·5 per cent. that of copper. Specific heat (25–100° C.), 0·109 c.g.s. units. Melting-point, 1390° C. Modulus of elasticity in tension, 31,000,000 lb. per sq. in.; in torsion, 10,300,000 lb. per sq. in.

Inconel has a high resistance to many corrosive agencies and is also heat resistant. It has been widely used for aero-engine exhaust manifolds, element sheaths for electric cooking apparatus, etc. It is only machinable with super-high-speed steel tools. Speed, 45 ft. per min., $\frac{1}{8}$-in. cut, $\frac{1}{32}$-in. feed.

Heat Treatment of Inconel.—After severe cold working, heat to 760° C. for $1\frac{1}{2}$ hours. This relieves stresses. For full annealing, heat to 980° C. for 10–15 minutes. The metal may be either furnace-cooled or quenched in water or dilute alcohol. The latter will give rather less oxidation of the surface.

Pickling of Inconel.—Hot solutions of dilute nitric acid with a fluoride or chloride content should be employed. Scrub during pickling.

Soft Soldering of Inconel.—Use tinsmith's solder with a neutral solution of zinc chloride as a flux.

Welding of Inconel.—May be by either gas or electric-arc processes. For gas welding, a flame with excess acetylene is required. Flux is not essential. For arc welding, use flux-coated electrodes.

Weight Calculation for Monel Metal.—Multiply thickness in inches by 46·5 to give weight per square foot in pounds.

Nickel-iron Alloys.—The high permeability nickel-iron alloys of magnetic type are of great industrial importance by reason of their high permeability. They contain broadly 35–80 per cent. nickel.

PROPERTIES OF SOME NICKEL-IRON MAGNETIC ALLOYS

Property	*Mumetal*	*Radiometal*
Electrical resistivity	42 microhms per c.c.	55 microhms per c.c.
Initial permeability	10,000–30,000	2000.
Maximum permeability	60,000–100,000	10,000–15,000.
Magnetising force for maximum	0·025–0·04 oersted	0·3–0·4 oersted.
Maximum flux density	8000–9000 gauss	15,600 gauss.
Magnetising force for B maximum	——	2–2·5 oersteds.
Coercive force for B maximum	0·03 oersted	0·3–0·4 oersted.
Hysteresis loss per c.c. per cycle for B maximum	40–60 ergs	350 ergs.
Total loss per pound for B = 10,000 gauss	——	0·45 watt.
Specific gravity	8·6	8·3.

COMPOSITIONS OF SOME NICKEL-IRON ALLOYS AND MECHANICAL PROPERTIES

Condition	*Ni*	*Mn*	*C*	*T.S.*	*El. Lim.*	*E.*	*R.A.*
				Tons per sq. in.	*Tons per sq. in.*	*Per cent. on 2 in.*	*Per cent.*
Rolled	26·0	1·5	0·2	35·0	5·3	50·0	70·7
Quenched	26·0	1·5	0·2	34·0	6·6	49·5	70·5
Rolled	30·0	1·5	0·15	40·0	11·9	39·5	69·7
Annealed	30·0	1·5	0·15	37·8	12·5	46·5	68·5
Quenched	30·0	1·5	0·15	36·5	10·2	44·2	70·5
Rolled	30·0	2·0	0·4	46·6	20·9	47·0	66·6
Annealed	30·0	2·0	0·4	45·0	15·6	46·5	66·4
Quenched	30·0	2·0	0·4	40·6	11·1	45·7	69·3
Rolled	32·3	2·3	0·12	36·6	13·3	37·5	65·6
Annealed	32·3	2·3	0·12	34·5	9·3	43·0	66·2
Quenched	32·3	2·3	0·12	31·5	8·3	39·5	64·7
Rolled	35·1	1·5	0·22	39·5	13·3	40·6	67·5
Annealed	35·1	1·5	0·22	37·9	13·3	42·0	67·3
Quenched	35·1	1·5	0·22	36·6	12·2	41·0	65·0
Rolled	36·0	0·5	0·08	34·25	16·2	36·3	65·6
Annealed	36·0	0·5	0·08	31·0	10·6	39·2	67·5
Quenched	36·0	0·5	0·08	30·0	8·9	38·0	58·3
Cold drawn	43·0	1·5	0·35	44·5	23·2	16·2	46·0
Rolled	45·0	1·5	0·37	47·6	17·8	40·1	51·1
Annealed	45·0	1·5	0·37	38·8	15·5	43·7	51·1
Quenched	45·0	1·5	0·37	31·2	8·6	38·0	46·3
Rolled	50·7	1·25	0·17	44·0	21·6	38·5	67·7

A characteristic composition for mumetal is 74 per cent. nickel, 20 per cent. iron, 5·3 per cent. copper, 0·7 per cent. manganese. Permalloy contains approximately 78·5 per cent. nickel and 21·5 per cent. iron. Invar contains 35–36 per cent. nickel, 0·5 per cent. carbon, 0·5 per cent. manganese. Expansibility of Invar is + 0·05 at 10° C., − 0·36 at 20° C., and − 1·26 at 30° C., the value being microns. This metal is widely employed in time-measuring instruments, tape and wire measures, surveying, and special split-construction aluminium-alloy pistons, on account of its low expansion coefficient.

INFLUENCE OF HEAT TREATMENT ON COEFFICIENT OF EXPANSION OF INVAR

Treatment (° C.)	*Brinell No.*	*Mean Coefficient* × 10^{-6}	
		° C.	
After forging	142	17–100	1·66
		17–250	3·11
Quenching at 830	196	18–100	0·64
		18–250	2·53
Quenching at 830 and tempering	250	15–100	1·02
		15–250	2·43
Heating to 830 for 19 hours and cooling to room temperature	114	15–100	2·01
		15–250	2·89

Heat Treatment of Invar Alloy.—Anneal at 750–850° C. If quenched in water, low-temperature anneal at 95–150° C., and slow cool to room temperature over a period of several months.

Nickel Bronze.—Nickel is added to bronze and allied alloy metals in percentages ranging from 0·5 to over 50 per cent. Typical alloy compositions and their uses are indicated in the following table.

CHARACTERISTIC NICKEL-BRONZE COMPOSITIONS AND APPLICATIONS

Ni	*Sn*	*Zn*	*Pb*	*Cu*	*P*	*Mn*	*Fe*	*Purpose*
1·5	11·5	0·5	—	Bal.	0·5	—	—	Axleboxes, slide valves.
1·0	10·5	0·5	—	,,	0·3	—	—	General purposes.
1·0	12·0	0·5	5·0	,,	0·3	—	—	Rolling-mill bearings.
6·0	11·0	0·5	—	,,	0·05	—	—	Safety valves and seats.
5·0	5·0	2·0	—	,,	0·03	0·25 (opt.)	—	Valves, gun mountings, etc.
3·5	6·5	2·0	—	,,	—	—	—	Valves, gun mountings, etc.
2·0	8·0	2·0	—	,,	—	—	—	Castings for nickel-plating.
2·0	5·0	6·0	10·0	,,	—	—	—	Refrigerator expansion valves.
0·5	4·5	—	28·0	,,	—	—	—	Refrigerator seals.
20·0	7·0	2·0	—	,,	—	0·25	Up to 1·0	Valve faces, hydraulic pump impellers, etc.
30·0	10·0	1·0	—	,,	—	0·25	Up to 1·0	Anti-corrosive bearings.
40·0	8·0	1·0	—	,,	—	0·25	Up to 1·0	Steam-valve faces.
1·0	5·0	0·5	28·0	,,	—	—	—	Leaded bearing bronze.
1·5	5·0	5·0	5·0	,,	—	—	—	Valve bodies.
1·0	7·0	4·0	6·0	,,	—	—	—	Railway wagon axleboxes.

In general these nickel bronzes have high strength, wear and shock resistance, improved mechanical properties at elevated temperatures, higher corrosion resistance, a wider range of pouring temperatures, greater pressure tightness and resistance to refrigerants, and admirable bearing surfaces, assuming the correct alloy for each application is chosen.

Magnesium Alloys.—These are divisible into cast and wrought types. They are employed for engineering applications demanding lightness and high specific tenacity, and for pyrotechnical or other purposes, whether in solid or powder form. Most British incendiary bombs are made from a magnesium alloy containing approximately 5 per cent. aluminium, with small percentages of zinc and manganese.

COMPOSITION AND PROPERTIES OF THE MAIN MAGNESIUM ALLOYS

Mg	*Si*	*Mn*	*Al*	*Zn*	*Ce*	*0·1% Proof Stress*	*Ult. Stress*	*Elong. % on 2 in.*	*Condition*
						Tons per sq. in.			
Bal.	1·0	—	—	—	—	3·3	6·3	3·0	Sand cast.
”	—	1·5	—	—	—	1·9	7·0	7·0	”
”	—	1·2	—	—	—	2·0	6·2	5·0	”
”	—	—	3·0	1·0	—	3·0	10·5	8·0	”
”	—	—	4·0	3·0	—	4·5	11·0	7·0	”
”	—	—	6·0	3·0	—	5·0	12·5	5·0	”
”	—	—	5·3–6·7	2·5–3·5	—	5·3	12·0	6·0	”
”	—	—	8·0	0·4	—	5·3	10·5	3·0	”
”	—	—	7–9	—	—	7·6	13·4	2·5	”
”	—	—	9·5	0·4	—	6·0	9·6	1·5	”
”	—	—	8·0	0·4	—	5·8	14·0	8·0	Die-cast.
”	—	—	9·5	0·4	—	6·0	12·5	3·0	”
”	—	—	9–11	—	—	9·8	13·8	1·0	”
”	—	1·5	—	—	—	10·0	18·0	3·0	Extruded.
”	—	1·2	—	—	—	13·4	18·7	7·0	”
”	—	1·5	—	—	—	8·0	15·0	7·0	Sheet.
”	—	1·2	—	—	—	7·1	14·3	16·0	”
”	—	2·0	—	—	0·5	8·0	17·0	15·0	”
”	—	—	—	4·0	—	7·0	14·0	10·0	”
”	—	—	2·0	1·0	—	6·5	13·0	10·0	”
”	—	—	3·0	1·0	—	7·5	17·0	12·0	”
”	—	—	3·3–4·7	—	—	9·8	16·0	10·0	”
”	—	—	6·0	1·0	—	15·0	20·0	12·0	Extruded.
”	—	—	5·8–7·2	0·4–1·0	—	13·0	17·8	16·0	”
”	—	—	6·0	1·0	—	8·0	15·0	5·0	Forged.
”	—	—	6·0	1·0	—	9·5	16·0	7·5	Tubular.
”	—	—	8·0	0·4	—	15·0	22·0	12·0	Forged.
”	—	—	7·8–9·2	0·2–0·8	—	15·6	21·0	12·0	”
”	—	—	10·2	—	—	16·0	22·0	6·0	Extruded.
”	—	—	4·0	—	—	7·0	16·0	10·0	Sheet.

Magnesium has a specific gravity approximately two-thirds that of aluminium. Coefficient of expansion is approximately that of the light aluminium alloys. Thermal conductivities of magnesium and its alloys are much lower, being 0·38 and 0·5 c.g.s. units for the pure metal and aluminium respectively. The alloys are not particularly corrosion resistant, though they may be slightly improved in this respect by additions of manganese, which must, however, not be high. Typical uses for magnesium-alloy castings include crankcases, pistons, propellers, etc.

Anti-friction Alloys.—It is not advisable to employ perfectly pure alloys as bearings, and as a rule two or more alloys are combined for this purpose. The

compositions of these alloys differ considerably, and are governed in the main by the circumstances of use. The principal metals employed include copper, tin, lead, and antimony. The white-metal bearing alloys are divisible into lead-base and tin-base alloys. The latter are termed Babbitt metals, and cover a wide range of compositions. Antimony is usually included in the composition of these white-metal bearing alloys. The table gives representative compositions and mechanical properties.

COMPOSITION AND PHYSICAL PROPERTIES OF WHITE-METAL BEARING ALLOYS

Tin	*Antimony*	*Copper*	*Lead*	*M.S.*	*Y.P.*	*Elong.*	*Br. No.*
				Tons per sq. in.		*% on 2 in.*	
93·0	3·5	3·5	—	5·12	3·569	11·6	24·9
90·9	4·52	4·56	—	5·7	1·9	11·0	17·0
86·0	10·5	3·5	—	6·65	4·372	7·1	33·3
83·0	10·5	2·5	4·0	5·60	4·284	—	34·5
80·0	11·0	3·0	6·0	5·70	4·640	—	32·1
60·0	10·0	1·5	28·5	5·04	3·696	—	27·1
65·5	14·1	2·0	18·2	5·6	4·573	—	22·5
40·0	10·0	1·5	48·5	4·58	3·660	—	21·8
20·0	15·0	1·5	63·5	5·48	4·016	—	31·3
19·8	14·6	1·5	63·7	5·43	3·770	—	21·0
78·0	11·0	11·0	—	6·36	4·550	—	37·0
5·0	15·0	—	80·0	4·69	3·590	2·8	24·9

Solders.—Normal plumber's solder is made up of 2 parts of lead and 1 part of tin. Tinsmith's solder comprises 2 parts tin and 1 part lead. Alloys may be manufactured having any required fusion point upwards of 60° C. A popular solder is 2 parts bismuth, 1 part each lead and tin, which melts at 93·7° C. Another is of 4 parts bismuth, 2 parts lead, 1 part tin, 1 part cadmium, which melts at 60·5° C. Standard American compositions include: 63 per cent. tin, 37 per cent. lead basis, but may contain 0·12 per cent. antimony, 0·08 per cent. copper, the basis metal percentages being modified accordingly; 49·25 per cent. tin, 50 per cent. lead, 0·75 per cent. antimony, 0·15 per cent. copper. In general, American soft solders range from 33 to 63 per cent. tin, 67 to 37 per cent. lead, in one group, and 31 to 49·25 per cent. tin and 67 to 50 per cent. lead in the second group. Antimony and copper are fixed at 0·12 and 0·08 respectively for the first group, but antimony ranges from 0·75 to 2·0 in the second group, copper being fixed at 0·15 per cent. None of these American soft solders contains zinc or aluminium, and their maximum impurity content is 0·1.

American sweating solders normally vary between 37·5 : 62·5 and 50 : 50 tin-lead. The most favoured composition is 40 : 60 and 45 : 55. This is a trade term implying that the per centual tin weight is placed first, the lead second.

There are, of course, many other soft solders.

Silver Solders.—These are alloys of silver, copper, and zinc used for brazing. Typical compositions are: silver 10 per cent., copper 52 per cent., zinc 38 per cent. basis; cadmium 0·5 per cent. (maximum) may be included; silver 80 per cent., copper 16 per cent., zinc 4 per cent. These represent the extremes of the silver range. The maximum impurity percentage is usually in the region of 0·15 per cent.

MAGNETIC CRACK DETECTION

The Magnetic Analyser.—Iron and steel are magnetic in most of their forms. If placed within an electrified coil, certain magnetic effects are produced upon them according to their magnetic permeability and their constitution. If two identical bars are placed inside two coils connected in series and identically wound as regards number of turns, identical magnetic effects will be produced unless either one of the metals, though believed identical in structure, is not so, or has a crack

or similar discontinuity. In such instances there will be a difference in the magnetic effect. This is the basis of magnetic crack detection. An oscillograph may be employed to indicate extremely slight variations.

Magnetising the Parts.—Methods: (*a*) Placing the bar to be tested in the magnetic circuit of an electro-magnet; (*b*) passing the part through a D.C. solenoid or coil.

The Detecting Fluid.—For swift and precise operation in workshops a detecting fluid is employed. This contains spongy iron particles holding a fair quantity of air, and therefore lightening their weight. The containing liquid is a hydrocarbon acid-free and water-free. The liquid is permitted to flow gradually over the surfaces being tested until the iron grains are attracted to the surface over the crack. This attraction is due to the interruption in the magnetic flux, causing polarity athwart the edges of the crack. A magnetic powder made up of chemically prepared, finely divided iron particles may also be used, in which case it is gently blown on to the affected surface, when, if a crack exists, the grains will congregate over it, making a line or ridge.

Recording Cracks as Detected.—Press dry white blotting-paper firmly and uniformly over the flawed surface while still moist from the liquid.

Alternatively, use a portable fluid detector, comprising a shallow round dish having a thin back and a transparent lid. This carries a solution of the iron powder, which, after shaking to stir up the mixture, is laid horizontally on the part to be tested. The iron grains will settle and align themselves on the bottom of the dish in accordance with the location of the flaw. This device has the advantage that after the necessary particulars have been taken it can be used again and again.

Demagnetising the Parts.—Most parts and bars have to be demagnetised after magnetic crack detection. Platen- or aperture-type demagnetisers may be used, but the latter are by far the speedier and more up to date.

DEMAGNETISER DIMENSIONS AND RATINGS

Aperture Size	*Approx. Current Consumption on 230 volts*
in.	*amperes*
18 × 18	30
18 × 15	30
18 × 12	28
18 × 9	27
15 × 15	27
12 × 12	23
12 × 6	9
9 × 5	6
6 × 6	5
6 × 3	4

DIECASTING

The Diecasting Process.—The molten metal, for example aluminium alloy, is forced into and maintained in a metal mould or die by hydrostatic pressure until it solidifies. The pressures employed may range from 400 to 2000 lb. per sq. in., according to the mass of the diecasting produced. The process is more fully dealt with in the section commencing on p. 301.

Advantages of Diecasting.—Parts rapidly turned out in homogeneous metal, identical appearance, and identical form and dimensions. Machining minimised by reason of accuracy to size, together with ability to cast threads and core holes. Studs, bushes and inserted pieces may be cast integrally. Thin and light sections may be cast. Higher strength and rigidity obtainable at less expense as compared with sheet-metal parts or stamped parts. Excellent surfaces produced, minimising cost of finishing work. Possibility of reproducing with accuracy elaborate designs. (See separate section.)

DRAUGHT ON DIECASTING CORES

Approximate Hole Diameter	*Draught per In. of Depth*
in.	*in.*
Below $\frac{1}{8}$	0·015–0·020
$\frac{1}{8}$–1	0·010
Over 1	0·010–0·03 on diameter

Small holes designed for tapping are, as a rule, cast to the root diameter of the thread, with standard draught added. Standard draughts may be cut down if desired, but this may mean a higher replacement rate for cores.

ALUMINIUM DIECASTING ALLOYS AND THEIR PROPERTIES

Cu	*Si*	*Ni*	*Al*	*Ult. Strength*	*Elong. % on 2 in.*	*Impact*	*Specific Gravity*
%	%	%	%	*tons per sq. in.*		*ft.-lb.*	
—	5·0	—	95·0	13·0	3·5	4·5	2·70
—	12·0	—	88·0	14·6	1·5	2·0	2·66
2·0	3·0	—	95·0	13·3	3·5	5·0	2·75
4·0	5·0	—	91·0	14·2	2·0	2·5	2·78
1·5	1·5	2·25	94·75	13·0	4·0	4·5	2·72
4·0	1·75	4·0	90·25	13·8	1·5	2·0	2·87
2·0	8·0	—	90·0	14·2	1·7	3·0	2·68
7·0	1·5	—	91·5	14·6	1·0	1·5	2·85

MAGNESIUM DIECASTING ALLOYS AND THEIR PROPERTIES

Al	*Mn*	*Si*	*Zn*	*Tensile Strength*	*Y.P.*	*Elong. % in 2 in.*	*Brinell No.*	*Izod*
%	%	%	%	*tons per sq. in.*	*tons per sq. in.*			*ft.-lb.*
10·0	0·13	0·5	—	13·3	9·7	1	62	1
9·0	0·13	0·2	0·6	14·6	9·2	3	60	2
8·0	0·15	0·3 (max.)	—	14·2	8·7	3	60	2
6·0	0·2	0·2 (max.)	—	11·8	7·2	4	50	3

ZINC DIECASTING ALLOYS AND THEIR PROPERTIES

Cu	*Al*	*Mg*	*Fe*	*Pb*	*Cad.*	*Tin*	*Zn*	*T.S.*	*E.*	*Br. No.*
%	%	%	%	%	%	%	%	*tons per sq. in.*	%	
0·1	3·5–4·3	0·03–0·08	0·1	0·007	0·005	0·005	Balance	16·6	4·7	60–90
2·5	3·5–4·5	0·02–0·1	0·1	0·007	0·005	0·005	Balance	21·4	5·1	75–100
0·75–1·25	3·5–4·3	0·02–0·08	0·1	0·007	0·005	0·002	Balance	19·4	3·0	70–85

TIN-BASE DIECASTING ALLOYS AND THEIR PROPERTIES

Tin	*Pb*	*Antimony*	*Cu*	*Approx. Melting Range*	
				Solid	*Liquid*
%	%	%	%	° C.	° C.
92·0	—	5·5	2·5	220	310
91·0	—	4·5	4·5	223	360
90·5	—	8·0	8·0	224	249
86·0	—	7·5	6·5	238	354
83·5	—	8·33	8·33	240	422
82·0	—	13·0	5·0	238	343
79·0	5·0	9·0	7·0	227	321
65·0	18·0	15·0	2·0	181	296
61·5	25·0	10·5	3·0	202	282
61·0	30·0	6·0	3·0	187	232
60·0	35·0	5·0	—	179	193
59·5	26·0	9·5–11·5	3·25	—	—

METALLURGICAL DATA

SURFACE TENSION OF SOME COMMON METALS

	Temperature, ° C.	*Surface Tension, Dynes per Cm.*
Antimony . .	640	350
Bismuth . . .	269	378
Cadmium . .	320	630
Copper . . .	1131	1103
Gold . . .	1120	1128
Iron (acc. to C. content)	1300–1420	1150–1500
Lead . . .	327	452
Mercury . . .	20	465
Silver . . .	998	923
Tin	232	526
Zinc . . .	419	758

Convenient Shop Formulæ for obtaining Weights of Steel Bars

Rounds: $\frac{(D \times 4)^2}{6}$ = Wt. in lb. per ft., D being diameter of bar. Alternatively $D^2 \times \frac{8}{3}$.

Squares: Square the section, add a 0, and divide by 3, to get wt. in lb. per ft. Alternatively, $S^2 \times \frac{17}{5}$, S being the section.

Flats: Multiply width by thickness, add a 0, and divide by 3, to get wt. in lb. per ft. Alternatively, $W \times T \times \frac{17}{5}$, W being width and T being thickness.

Points on Ordering Steels.—Tool steels are always supplied annealed unless otherwise specified. Constructional steels, whether plain carbon or alloy, can be supplied either as rolled or heat treated to specified strengths. With steels of high-tensile strength it is advisable to state the actual tonnage required, as many alloy steels can be heat treated to give an extremely wide range of physical properties.

Quantities should be stated in bars or by weight, but if a fixed or dead length is required, extra will be charged to cover wastage and labour involved in trimming the bar down to exact length. Tool-steel bars are usually 8–12 ft. long. Constructional steel bars range from 15 to 20 ft.

When stainless steels are ordered, indicate if the material is required with black finish, descaled finish, mirror polish, or any other type of finish. Round bars can

be supplied either black hot rolled or precision ground to tolerances down to 0·0005 in. overall. Sheets are supplied either fully softened and descaled, dull polished, or mirror finished. There are several grades of mirror polish.

STANDARD RANGE OF BUTT-WELDED ANNEALED RECTANGULAR HIGH-SPEED STEEL BLANKS FOR CUTTING TOOLS

Section	*Overall Length*	*Approx. Tip Length*	*Section*	*Overall Length*	*Approx. Tip Length*
in.	*in.*	*in.*	*in.*	*in.*	*in.*
½ sq.	4	½	1 × ½	8	[illegible]
⅝ sq.	4½	⅝	1 × ⅝	8	[illegible]
¾ sq.	6	$\frac{13}{16}$	1 × ¾	8	[illegible]
⅞ sq.	8	$\frac{13}{16}$	1¼ × ¾	10	1$\frac{1}{16}$
1 sq.	8	1	1¼ × ⅞	10	1$\frac{1}{16}$
1¼ sq.	12	1¼	1½ × 1	12	1⅛
1½ sq.	12	1½	1¾ × 1¼	14	1½
¾ × ⅝	5½	$\frac{11}{16}$	2 × 1½	16	1¾

Binding and Tearing of Taps.—Usually due to pitch error resulting from distortion after hardening. It may be corrected by grinding the thread form. To remove slight imperfections or burrs on the thread form, tap a hole in mild-steel plate and run the tap backwards and forwards a few times with a lubricant of oil and flour of emery powder. Grinding the front of the taps gun-nosed is always an advantage when tapping blind holes, as it throws the chips forward and keeps the thread clear when backing the tap from the hole.

Proportions of Ingots and Castings of Steel, made by Different Processes in 1936

	tons
Acid Bessemer	238,600
Basic Bessemer	323,600
Acid open-hearth	2,111,800
Basic open-hearth	8,760,600
Electric arc	152,600
Other processes	197,400
	11,784,600

ANNEALING OVENS ON WHITE HART MALLEABLE IRON USING LUMP COAL. COMPARATIVE DATA ON FIRING METHODS

	Hand Firing	*Pulverised Fuel Firing*
Maximum charge of castings per oven	6·5 tons	10 tons
Fuel per ton of castings annealed	25 cwts.	12 cwts.
Price of fuel per ton (1939)	26s.	15s.
Cost of fuel per ton of castings annealed	32s. 6d.	9s.
Cost of power per ton of castings annealed	—	4s. 6d.
Cost of repairs and renewals per ton of castings annealed	—	9d.
Total cost of firing, excluding capital charges and depreciation	32s. 6d.	14s. 3d.
Saving per ton of castings annealed	—	18s. 3d.

Tungsten Alloy for Arcing Contacts.—May be either forged or cast. Drop forging is possible, but not easy. Conductivity, $4 \cdot 1 \times 10^{-5}$ ohms, as compared with copper $1 \cdot 7 \times 10^{-5}$ ohms. Brinell hardness, 240. The material is easily machinable, and may be brazed to mild steel in exactly the same way as high-speed steel. Is satisfactory for breaking high voltages, especially in oil switches, but is not advised for use in connection with high amperages. It may be easily drilled as supplied, but must be heated up if it is desired to bend it to shape, and after bending must be annealed at 850–900° C. Extrusion is not practicable, and it is usual to cast or machine any special shape of contact.

Heat-resisting Steel for Pyrometer Sheaths.—0·7–1 per cent. silicon, 0·2–0·4 per cent. manganese, 24–26 per cent. chromium, 12–14 per cent. nickel. Tests on a special low-carbon-purity steel of this type gave the following results:

Dimensions of Testpiece (in.)	*Temperature of Spelter Bath in ° F.*	*Number of Hours in Bath*
1·0	860	0
0·9875	860	170
0·981	860	290
0·972	860	452
0·967	860	567
0·956	860	660
0·945	860	827
0·935	860	1103
0·920	860	1275
0·910	860	1413
0·902	860	1597

Protecting Surface of Polished Stainless-steel Sheet during Forming.—Use highly polished dies. Lubricant: lithopone and linseed oil or sheet of thin paper between die and polished steel. Remove film of iron with HNO_3 passivation treatment, or buffing compounds.

Negradising.—An anti-rusting process, in which a chemical reaction takes place on the surface of steel and iron, changing them into ferroso-ferric-oxide, an extremely good corrosion inhibitor. The process gives the articles a pleasing black appearance. The protecting layer is produced by dipping the articles in a solution made up merely by mixing the negradising FO salts in water. The layer produced protects the steel and iron parts from corrosion. Dimensions are not noticeably altered. Fine mechanical as well as heavy parts can be treated. Physical properties remain unchanged. Large quantities may be dealt with. No complicated apparatus required. Unskilled labour may be employed.

Metals for treatment must be cleaned before dipping, being either brushed, scoured, or pickled. Rinse off all pickling-bath residues with water before dipping. Degreasing is not needed, unless old grease or heavy grease is present. Temperature for working is 260–302° F., according to thickness and hardness of metal. Processing time: 5–20 minutes, according to surface conditions. Rinse in water after dipping. Use rinsing water for replenishing dipping tank after evaporation. Then dip in another special rinsing tank, rinse again in water, dry, and oil, paint, or lacquer, as required. Process has been developed by Protective Metal Finishes, Ltd., 146, St. John Street, London, E.C.1.

Gunmetal Finish.—Place parts loosely in retort with a little charred bone and heat to 370–425° C. When fully oxidised, the parts may be allowed to fall to about 345° C. Add a mixture of bone and 1–2 tablespoonfuls of carbonia oil, and heat for several hours. Dip in sperm oil or tumble in oil-cork to get an even black finish.

Blue Finish.—Place parts in a bed of hot charcoal about 2 ft. deep. When the right shade of blue is attained, rub parts vigorously with waste dipped in raw sperm oil.

Brown Finish.—Clean parts thoroughly by boiling for 15 minutes in soda solution. Dry in a rack. When cooled to about 50° C. coat with a browning solution, e.g. 3·9 per cent. ferric chloride, 1·2 per cent. mercuric chloride, 0·6 per cent. cupric sulphate, 1·8 per cent. nitric acid, 6·2 per cent. spirits of nitre, 4·0 per cent. alcohol, 82·3 per cent. water. Dry for 30 minutes, give second coat and dry for 30 minutes more. Place in warming room and heat to 60–80° C. Transfer to rusting room at 80° C. Rust for about 1 hour or less, according to size and type of part. Remove to third room to set rust, and leave for 30 minutes. Place in clean boiling water for 15 minutes. Drain dry and card on wire brush or fibre wheel to remove oxide. Treat similarly three more times, then coat browned surfaces with slushing oil.

Brinell's Hardness Numbers

(Diameter of Steel Ball, 10 mm. Pressure, 3000 Kg.)

Diameter of Ball Impression	*Hardness Number*	*Calculated Tonnage*	*Diameter of Ball Impression*	*Hardness Number*	*Calculated Tonnage*	*Diameter of Ball Impression*	*Hardness Number*	*Calculated Tonnage*
mm.			*mm.*			*mm.*		
2	946	206	3·70	269	59	5·35	124	28·5
2·05	898	196	3·75	262	57	5·40	121	28
2·10	857	187	3·80	255	55	5·45	118	27
2·15	817	178	3·85	248	54	5·50	116	26·5
2·20	782	171	3·90	241	52	5·55	114	26
2·25	744	162	3·95	235	51	5·60	112	25·5
2·30	713	155				5·65	109	25
2·35	683	149	4	228	50	5·70	107	24·5
2·40	652	142	4·05	223	49	5·75	105	24
2·45	627	136	4·10	217	47	5·80	103	23·5
2·50	600	131	4·15	212	46	5·85	101	23
2·55	578	126	4·20	207	45	5·90	99	22·75
2·60	555	121	4·25	202	44	5·95	97	22·5
2·65	532	116	4·30	196	43			
2·70	512	112	4·35	192	42	6	95	22
2·75	495	108	4·40	187	41	6·05	94	21·5
2·80	477	104	4·45	183	40	6·10	92	21
2·85	460	100	4·50	179	39·5	6·15	90	20·75
2·90	444	97	4·55	174	39	6·20	89	20·5
2·95	430	94	4·60	170	38·5	6·25	87	20
			4·65	166	38	6·30	86	19·75
3	418	91	4·70	163	37·5	6·35	84	19·25
3·05	402	88	4·75	159	36·5	6·40	82	19
3·10	387	84	4·80	156	36	6·45	81	18·75
3·15	375	82	4·85	153	35	6·50	80	18·5
3·20	364	79	4·90	149	34	6·55	79	18·25
3·25	351	76	4·95	146	33·5	6·60	77	17·75
3·30	340	74				6·65	76	17·5
3·35	332	72	5	143	33	6·70	74	17
3·40	321	70	5·05	140	32	6·75	73	16·75
3·45	311	68	5·10	137	31·5	6·80	71·5	16·5
3·50	302	66	5·15	134	31	6·85	70	16·25
3·55	293	64	5·20	131	30	6·90	69	16
3·60	286	62	5·25	128	29·5	6·95	68	15·75
3·65	277	60	5·30	126	29			

TABLE OF ELEMENTS

Element	*Symbol*	*Atomic No.*	*Atomic Wt.*	*Density (lb./in.³ 20° C.)*	*Melting-point (° F.)*	*Linear Coefficient of Expansion/° C. at Normal Temp.*	*Heat Conductivity cal./cm.²/cm./° C./sec. at Normal Temp.*	*Electrical Resistivity (Microhm-cm.)*
Actinium	Ac	89	227	—	3272	10^{-6}	—	—
Aluminium	Al	13	26·97	0·0975	1214·6	24	0·52	2·655
Antimony	Sb	51	121·76	0·2391	1166·9	11·29	0·0444	39
Argon	A	18	39·944	$6{\cdot}008 \times 10^{-5}$	− 306·2	—	$0{\cdot}406 \times 10^{-4}$	—
Arsenic	As	33	74·91	0·2071	1497	3·86	—	35
Barium	Ba	56	137·36	0·1265	1562	—	—	—
Beryllium	Be	4	9·02	0·0658	2345	12·3	0·3847	18·5
Bismuth	Bi	83	209·00	0·3541	519·8	13·45	0·0200	115
Boron	B	5	10·82	0·0831	4172	2	—	$1{\cdot}8 \times 10^{12}$
Bromine	Br	35	79·816	0·1127	19·04	—	—	—
Cadmium	Cd	48	112·41	0·3125	609·6	29·8	0·217	7·59
Calcium	Ca	20	40·08	0·0560	1564	25	—	4·6
Carbon (Graphite)	C	6	12·01	0·0802	—	1·2	0·057	1000
Cerium	Ce	58	140·13	0·2493	1427	—	—	78
Cesium	Cs	55	132·91	0·0686	78·8	97	—	20
Chlorine	Cl	17	35·457	—	− 150·88	11·44	$0{\cdot}172 \times 10^{-4}$	10×10^{15}
Chromium	Cr	24	52·01	0·2579	2822	8·1	0·165	13·1
Cobalt	Co	27	58·94	0·3216	2714	12·08	0·165	9·7
Columbium	Cb	41	92·91	0·3096	3542	7·2	—	20
Copper	Cu	29	63·57	0·323	1981·4	16·42	0·923	1·682
Dysprosium	Dy	66	162·46	—	—	—	—	—
Erbium	Er	68	167·2	—	—	—	—	—
Europium	Eu	63	152·0	—	—	—	—	—
Fluorine	Fl	9	19·00	—	− 369·4	—	—	—
Gadolium	Gd	64	156·9	—	—	—	—	—
Gallium	Ga	31	69·72	0·2135	85·6	18·3	—	57·1
Germanium	Ge	32	72·60	0·1937	1757·3	—	—	89×10^{3}
Gold	Au	79	197·2	0·6973	1945·4	14·4	0·7072	2·42

Hafnium	Hf	72	178·6	0·4118	3092	—	—	—
Helium	He	2	4·003	$0·6008 \times 10^{-5}$	$<-458·0$	—	$3·32 \times 10^{-4}$	—
Holmium	Ho	67	163·5	—	—	—	—	—
Hydrogen	H	1	1·0081	$0·3026 \times 10^{-5}$	$-434·4$	—	$4·06 \times 10^{-4}$	—
Illinium	Il	61	—	—	—	—	—	—
Indium	In	49	114·76	0·264	322	33	0·057	9
Iodine	I	53	126·92	0·178	236·3	93	$10·4 \times 10^{-4}$	$1·3 \times 10^{15}$
Iridium	Ir	77	193·1	0·809	4368	6·41	0·141	6·08
Iron	Fe	26	55·84	0·284	2795	11·9	0·19	9·8
Krypton	Kr	36	83·7	$3·502 \times 10^{-3}$	$-275·22$	—	$0·212 \times 10^{-4}$	—
Lanthanum	La	57	138·92	0·222	1518·8	—	—	59
Lead	Pb	82	207·21	0·409	621·2	29·5	0·083	20·65
Lithium	Li	3	6·940	0·0193	366·8	56·0	0·17	8·5
Lutecium	Lu	71	175·0	—	—	—	—	—
Magnesium	Mg	12	24·32	0·0628	1204	25·7	0·37	4·46
Manganese	Mn	25	54·93	0·268	2268	23	—	—
Masurium	Ma	43	—	—	—	—	—	—
Mercury	Hg	80	200·61	0·489	$-38·0$	—	0·0200	95·8
Molybdenum	Mo	42	95·95	0·368	4748	5·49	0·350	4·77
Neodymium	Nd	60	144·27	0·255	1544	—	—	79
Neon	Ne	10	20·183	$3·030 \times 10^{-5}$	$-415·498$	—	$1·092 \times 10^{-4}$	—
Nickel	Ni	28	58·69	0·322	2646	13·7	0·140	6·9
Nitrogen	N	7	14·008	$4·209 \times 10^{-5}$	$-345·87$	—	$0·600 \times 10^{-4}$	—
Osmium	Os	76	190·2	0·812	4892	5·70	—	9
Oxygen	O	8	16·0000	$4·8122 \times 10^{-5}$	$-361·12$	—	$0·589 \times 10^{-4}$	—
Palladium	Pd	46	106·7	0·433	2831	11·60	0·161	10
Phosphorus	P	15	31·02	0·0657	111·4	11·25	—	10^{17}
Platinum	Pt	78	195·23	0·0774	3224	8·8	0·166	9·83
Polonium	Po	84	—	—	—	—	—	—
Potassium	K	19	39·096	0·031	144·1	—	0·237	7·0
Praesodymium	Pr	59	140·92	0·239	1724	8·3	—	88
Protoactinium	Pa	91	231	—	—	—	—	—
Radium	Ra	88	226·05	0·1808	1760	—	—	—
Radon	Rn	86	222	0·159	$-95·8$	—	—	—
Rhenium	Re	75	186·31	0·723	5432	—	—	21
Rhodium	Rh	45	102·91	0·449	3571	8·9	0·213	4·93
Rubidium	Rb	37	85·48	0·0553	101	90·0	—	12·5
Ruthenium	Ru	44	101·7	0·441	4442	8·5	—	10
Samarium	Sm	62	150·43	0·28	>2400	—	—	—

TABLE OF ELEMENTS—*continued*

Element	*Symbol*	*Atomic No.*	*Atomic Wt.*	*Density (lb./in. 20° C.)*	*Melting-point (° F.)*	*Linear Coefficient of Expansion/° C. at Normal Temp.*	*Heat Conductivity cal./cm.²/cm./° C./sec. at Normal Temp.*	*Electrical Resistivity (Microhm-cm.)*
Scandium . .	Sc	21	45·10	0·09	2200	—	—	—
Selenium . .	Se	34	78·96	0·174	428	87·0	—	12
Silicon . .	Si	14	28·60	0·087	2600	—	0·20	85×10^{3}
Silver . .	Ag	47	107·880	0·38	1761	18·9	0·974	1·62
Sodium . .	Na	11	22·997	0·035	207·5	71·0	0·3225	4·6
Strontium . .	Sr	38	87·63	0·094	1420	—	—	22·76
Sulphur . .	S	16	32·06	0·075	235·4	67·48	0·00063	$1{\cdot}9 \times 10^{17}$
Tantalum . .	Ta	73	180·88	0·60	5462	6·5	0·130	15·5
Tellurium . .	Te	52	127·61	0·224	846	16·8	0·01433	—
Terbium . .	Tb	65	159·2	—	590	—	—	—
Thallium . .	Tl	81	204·39	0·428	578	28·0	0·09315	18·1
Thorium . .	Th	90	232·12	0·416	3353	12·3	—	18
Thulium . .	Tm	69	169·4	—	—	—	—	—
Tin . .	Sn	50	118·70	0·264	449·6	—	0·157	11·5
Titanium . .	Ti	22	47·90	0·163	3272	7·14	—	—
Tungsten . .	W	74	183·92	0·698	6098	4·0	0·476	5·48
Uranium . .	U	92	238 07	0·676	3074	—	—	60
Vanadium . .	V	23	50·95	0 205	3110	—	—	26
Xenon . .	Xe	54	131·3	$5{\cdot}517 \times 10^{-3}$	— 169·6	—	$1{\cdot}24 \times 10^{-4}$	—
Ytterbium . .	Yb	70	173·04	—	—	—	—	—
Yttrium . .	Y	39	88·92	0·199	2700	—	—	—
Zinc . .	Zn	30	65·38	0·258	787	—	0·268	—
Zirconium . .	Zr	40	91·22	0·23	3092	6·3	—	41

SPECIFIC HEATS AND MELTING-POINTS

Material	Average Specific Heat	Average Watt-hours per lb. per °C.	Heat of Fusion Watt-hours per °C.	Melting-point, °C.	Lb. per cu. ft.	Specific Electric Resistance (Normal Temperature)	Relative Conductance (Normal Temperature)
Air (20° C.)	0·237	0·125	—	—	0·08074	—	—
Aluminium	0·22	0·116	45·9	660	160	2·828	60·97
Brass	0·091	0·048	—	850–1200	511–536	6–9	28·7–19·1
Carbon	0·204	0·107	—	—	—	—	—
Cobalt	0·107	—	—	1480	—	9·7	17·7
Constantan	—	—	—	—	—	49	3·52
Copper	0·094	0·0495	22·8	1083	555	1·7241	100
German Silver	—	—	—	—	—	30–40	5·7–4·3
Graphite	0·20	0·105	—	—	120–140	—	—
Cast Iron	0·11–0·16	0·058–0·116	12·2	1200	450	—	—
Lead (solid)	0·031	0·0163	3·1	327·4	710	22	7·8
Lead (liquid)	0·0471	0·0248	—	—	—	—	—
Manganin	—	—	—	—	—	44	3·9
Mercury	0·03312	—	—	—	—	95·8	1·8
Molybdenum	0·0659	—	—	2621	—	5·7	30·3
Nichrome	—	—	—	—	—	100	1·724
Nickel	0·11	0·058	2·45	1452	517–573	7·8	22·1
Paraffin (solid)	0·62–0·69	0·326–0·363	—	38–56	54·25–56·75	—	—
Paraffin (liquid)	0·71	0·374	18·5	—	52·4–57	—	—
Pitch	—	—	—	—	67	—	—
Platinum	0·03243	—	—	1755	—	10	17·24
Silver	0·0557	—	—	960·5	—	1·62	106·4
Solder	—	—	5·30–9·0	205–185	555–520	—	—
Tallow	—	—	—	33·3	57–60·5	—	—
Tar	—	—	—	—	62–63·4	—	—
Tin (solid)	0·056	0·0295	7·4	232	455	—	—
Tin (liquid)	0·064	0·0337	—	—	436	—	—
Tungsten	0·035	—	—	3370	—	5·4	31·9
Type Metal	0·039	0·0206	—	—	660	—	—
Water (20° C.)	1·0	0·527	42·3	0	62·42	—	—
Wax, Bee's	—	—	22·4	61–68	60–61	—	—
Zinc (cast)	0·093–0·12	0·049–0·063	14·8	419·4	439–446·5	—	—
Zinc (liquid)	—	—	—	—	404	—	—

APPROXIMATE WEIGHT OF 1 CUBIC INCH OF METALS

	Lb.		Lb.
Platinum	0·78	Nickel	0·31
Gold	0·69	Wrought iron	0·28
Mercury	0·49	Steel	0·28
Lead	0·41	Cast iron	0·26
Silver	0·36	Tin	0·26
Bismuth	0·35	Zinc	0·26
Copper	0·32	Antimony	0·24
Brass	0·31	Aluminium	0·097
Magnesium	0·063	Duralumin	0·101

Physical Constants of the Alloy-forming Elements

Element	*Atomic Weight*	*Approx. Melting-point °C.*	*Approx. Boiling-point °C.*	*Density, g. per c.c. 20° C.*	*Atomic Volume, c.c. per gram-atom*	*Mean Linear Expansion Coefficient, per ° C. × 10⁶ (20° C.)*	*Specific Heat Calories (15°) per g. per 1° C. at room temp.*	*Electrical Resistivity, Microhms per c.c. 20° C.*	*Crystallisation, Shrinkage per cent.*	*Young's Modulus of Elasticity, lb. per sq. in. × 10⁶*	*Thermal Conductivity at 0° C. Calories per c.c. per sec. per ° C.*
Aluminium	26·97	660	1800	2·702	9·98	23·03	0·214	2·655	6·7	10	0·485
Antimony	121·77	630	1380	6·684	18·22	11·4	0·049	39	1·4	11	0·044
Arsenic	74·96	815	616	5·7 M.H.	13·2	4·7	0·0822	35	—	—	—
Beryllium	9·02	1349	1499	1·8	5·0	—	0·427	18·5	—	—	0·79
Bismuth	209·0	270	1449	9·8	21·33	13·3	0·0293	115	−3·3	4·6	0·020
Cadmium	112·41	320	768	8·6	13·1	29·8	0·060	7·5	4·7	10·0	0·223
Calcium	40·07	810	1171	1·55	25·9	25	0·155	4·6	—	—	0·32
Carbon	12·00	—	4204	—	—	—	—	1000	—	—	—
Cerium	140·13	640	1399	6·90	20·33	—	0·0423	78	—	—	0·019
Chromium	52·01	1616	2204	7·1	7·3	8·2	0·106	2·6	—	—	0·560
Cobalt	58·97	1480	2871	8·9	6·6	12·3	0·1005	9·7	—	—	0·150
Copper	63·57	1083	2299	8·92	7·13	16·6	0·0921	1·69	4·1	17·8	0·927
Diamond	—	—	—	3·51	3·42	0·9	0·121	5 × 10²⁰	—	—	—
Gold	197·2	1063	2593	19·3	10·22	14·2	0·0311	2·4	5·2	11·1	0·707
Graphite	—	3482	—	2·255	5·32	8·0	0·169	1400	—	—	0·0375
Indium	114·8	154	1449	7·3	15·7	33	0·0568	9	—	—	0·162
Iridium	193·1	2350	4799	22·4	8·62	6·5	0·0323	6	—	71	0·141
Iron	55·84	1535	2887	7·86	7·10	11·7	0·107	10	—	30	0·148
Lead	207·20	327·4	1621	11·34	18·27	29·1	0·0306	21·9	3·4	1	0·084
Lithium	6·939	185	1199	0·53	13·1	56	0·79	9·3	1·5	—	0·167
Magnesium	24·32	651	1110	1·74	14·0	25·6	0·25	4·46	4·2	6·25	0·370
Manganese	54·93	1260	1899	7·2	7·6	23	0·107	5	—	—	0·291
Mercury	200·61	—	358	13·5465	14·810	182	0·0334	—	3·75	—	0·020
Molybdenum	96·0	2621	3704	10·2	9·4	4	0·065	4·77	—	—	0·349
Nickel	58·69	1452	2899	8·90	6·59	12·8	0·105	6·9	—	30	0·140
Osmium	190·8	2704	5299	22·48	8·488	6·1	0·031	9	—	—	0·162
Palladium	106·7	1555	2199	12·0	8·9	11·8	0·0587	10·8	—	14	0·161
Phosphorus	31·024	43·5	280	1·82–2·20	17·1–14·1	125	0·18–0·19	10¹⁷	—	—	—
Platinum	195·23	1755	4299	21·45	9·102	8·9	0·0324	10·5	—	23·5	0·166
Rhodium	102·91	1970	2482	12·5	8·2	8·4	0·058	5·1	—	42	0·214
Ruthenium	101·7	2449	2699	12·2	8·3	9·1	0·061	10	—	—	0·145
Silicon	28·06	1421	2599	2·4	11·7	2·8–7·3	0·176	85 × 10³	—	—	—

Physical Constants of the Alloy-forming Elements—*Continued*

Silver .	107·880	960·5	1949	10·5	10·3	18·9	0·0558	1·62	5·0	10·3	1·00
Sulphur	32·065	113	444	2·07–1·96	15·5–16·4	64	·171–·179	$2 \times 10^{[illegible]}$	—	—	0·0005
Tantalum	181·5	2849	4099	16·6	10·93	7	0·036	15	—	27	0·130
Thorium	232·15	1845	2982	11·2	20·7	—	0·0276	18	—	—	0·081
Tin .	118·70	232	2260	5·75–7·31	20·64–16·24	20	0·0542	11·4	2·7	5·9	0·157
Titanium	47·9	1799	2982	4·5	10·7	—	0·144	3	—	—	0·485
Tungsten	184·0	3370	5899	19·3	9·58	4	0·034	5·48	—	—	0·382
Uranium	238·17	1849	—	18·7	12·7	—	0·028	60	—	60	0·0243
Vanadium	50·96	1710	2982	5·96	8·55	—	0·115	—	—	—	—
Zinc .	65·38	419·4	907	7·14	9·16	33	0·0925	6	6·5	12·4	0·270
Zirconium	91	1699	2899	6·4	14·2	—	0·0662	170	—	—	0·0086

A Table of Principal Elements arranged in Order of Valency

	Name	Symbol	Atomic Weight
Monovalent	Bromine	Br	79·816
	Chlorine	Cl	35·457
	Fluorine	Fl	19
	Hydrogen	H	1·008
	Iodine	I	126·92
	Potassium	K	39·096
	Silver	Ag	107·88
	Sodium	Na	22·997
Divalent	Barium	Ba	137·36
	Cadmium	Cd	112·41
	Calcium	Ca	40·08
	Copper	Cu	63·57
	Magnesium	Mg	24·32
	Mercury	Hg	20·61
	Oxygen	O	16
	Zinc	Zn	65·38
Trivalent	Aluminium	Al	26·97
	Bismuth	Bi	209·00
	Boron	B	10·82
	Cobalt	Co	58·94
	Gold	Au	197·2
	Iron	Fe	55·84
	Nickel	Ni	58·69
Tetravalent	Carbon	C	12·01
	Lead	Pb	207·21
	Platinum	Pt	195·23
	Silicon	Si	28·60
	Tin	Sn	118·7
Pentavalent	Antimony	Sb	121·76
	Arsenic	As	74·91
	Nitrogen	N	14·008
	Phosphorus	P	31·02
Hexavalent	Chromium	Cr	52
	Manganese	Mn	54·93
	Sulphur	S	32·06

LINEAR EXPANSION COEFFICIENTS PER 1° C. (MULTIPLIED BY 10^6)

Metal	Temperature, ° C.											
	0–100	0–200	0–300	0–400	0–500	0–600	100–200	200–300	300–400	400–500	500–600	600–700
Armco iron	12·2	12·8	13·4	13·9	14·5	—	—	—	—	—	—	—
Cast iron	10·4–11·1	11·1–11·6	11·7–12·2	12·3–12·7	12·9–13·2	—	—	—	—	—	—	—
Electrolytic iron	12·0	—	13·3	—	—	14·7	13·0	14·5	15·3	15·9	16·8	17·4
Carbon steels (cast)	11·9	12·6	13·3	14·0	14·7	—	—	—	—	—	—	—
Carbon steels (forged)	11·4–12·2	11·8–12·8	12·5–13·4	13·2–14·0	13·9–14·4	—	—	—	—	—	—	—
Carbon steels (rolled)	11·8–12·8	12·4–13·3	13·0–13·9	13 6–14·4	14·2–14·9	—	—	—	—	—	—	—
Chromium-molybdenum steels (annealed)	11·1	11·7	12·3	13·0	13·6	—	—	—	—	—	—	—
Chromium-vanadium steels (annealed)	11·6	—	12·7–12·9	—	—	14·0–14·6	12·5–12·6	13·7–14·2	14·6–16·0	15·2–15 9	16·0–16·4	15·8–16 9
Nickel-chromium steels (Q. and T.)	11 5–11·8	12·1–12·3	12·7–12·9	13·3–13·4	13·9–14·0	—	—	—	—	—	—	—
Nickel steels (3·59%)	10·9	11·6	12·1–12·3	12·9	13·6	—	—	—	—	—	—	—
Nickel steels (5%)	11·5	12·0	12·4	12·9	13·4	—	—	—	—	—	—	—
Nickel steels (36½%)	2·9 (20–126° C.)	—	—	—	10·9 (20–506° C.)	—	—	—	—	—	—	14·6 (20–971° C.)
Screw stock (O.H.)	11·1–12·2	12·8	12·7–13·5	14·2	14·8	14·3–14·5	12·2–12·5	14·2–14·6	15·4–16·3	15·7–16·1	15·1–16·0	16·6–16·7
Stainless steels (13% Cr)	10·0	—	11·0	—	—	12·0	10·6	12·0	12·6	13·5	13·9	13·7
Stainless steels (18% Cr, 8% Ni)	17·3	—	—	—	—	—	—	—	—	—	—	20·2

Relative Conversion Table of Hardness Values

	Rockwell	Vickers Diamond	Scleroscope	Rockwell	Vickers Diamond	Scleroscope
1/16-in. Ball—100 Kg.	84–B	159	24	C–33	316	44
	85–B	163	25	C–34	327	45
	86–B	166	25	C–35	339	46
	87–B	170	26	C–36	350	48
	88–B	174	26	C–37	363	49
	89–B	179	27	C–38	375	51
	90–B	183	27	C–40	389	52
	91–B	187	28	C–41	404	54
	92–B	192	28	C–42	420	55
	93–B	197	29	C–44	437	57
	94–B	202	30	C–45	454	59
	95–B	207	30	C–46	472	61
	96–B	217	31	C–47	494	63
	97–B	223	32	C–49	515	65
120° Cone—150 Kg.	C–21	229	33	C–50	540	67
	C–22	235	34	C–52	567	70
	C–23	241	35	C–53	598	72
	C–24	248	36	C–55	633	75
	C–25	256	37	C–57	675	78
	C–26	263	37	C–58	717	81
	C–28	270	38	C–60	765	84
	C–29	279	39	C–62	820	87
	C–30	287	40	C–64	885	91
	C–31	296	42	C–66	960	95
	C–32	305	43	C–68	1050	100
				C–70	1150	106

DURALUMIN

Chemical Composition (B Grade)

Copper: 3·5 to 4·5 per cent. Magnesium: 0·4 to 0·7 per cent.
Manganese: 0·4 to 0·7 per cent. Aluminium: About 94·5 per cent.

For special purposes other grades (A, M, and H) are supplied. These vary somewhat in composition, according to the purpose for which they are intended.

Physical Properties (B Grade)

Specific Gravity: Approximately 2·8.
Specific Heat: 0·214 (Water = 1).
Thermal Conductivity: 31 (Silver = 100).
Electrical Conductivity: Normalised 33 to 35 per cent. (Copper = 100). Annealed 39 to 41 per cent. (Copper = 100).
Coefficient of Linear Expansion: 0·00001255 per degree Fahrenheit; 0·0000226 per degree Centigrade.
Young's Modulus of Elasticity (E): 4,500 tons per square inch.
Melting Range: 560 to 650 degrees Centigrade.
Annealing Range: 360 to 400 degrees Centigrade.
Heat Treatment or Normalising Temperature: 480 degrees Centigrade ± 10 degrees C.
Forging Temperature: 400 to 470 degrees Centigrade.

Mechanical Properties

Brinell Hardness: Annealed, 60 (approx.). Normalised, 90 to 115.
Fatigue Range: ± 9·5 tons per square inch.
Izod Impact Value: About 15 ft.-lb.

STEEL TUBES

Seamless

Types : Hot Formed.—Solid billets of suitable length and of either round or square section, according to the process used, are heated to forging temperature and holes are pierced through them, converting them into thick-walled tubes or hollow blooms.

The piercing is done either by placing the solid billets in a press and forcing a mandrel fitted with a suitable point through the centres, or by rotating the billets between rolls or discs which are set at an angle to give a forward motion. The pressure exerted by the rolls or discs together with the rotation cause the billets to become hollow, and a mandrel, located at the end of the rolls, and over which the now hollow-centred blooms are fed, controls the wall thickness of the blooms.

The next step is to convert these thick-walled tubes or hollow blooms into longer and thinner-walled tubes. This is also done in the hot stage, either by forcing the hollow blooms through a series of dies or by passing them through a series of rolls or by putting them through a Pilger mill which forges the tubes to the desired size. In each of these operations the hollow billets are supported inside on mandrels, so that the finished sizes can be fairly closely controlled.

Size Range.—These hot-finished tubes can be made in a wide range of carbon and alloy steels, from $1\frac{1}{2}$ in. to 16 in. diameter, for normal supplies, but tubes as large as 40 in. diameter have been specially produced. When smoother surfaces or closer dimensions or smaller sizes are required, they are cold drawn.

Cold Drawn

The hot-finished tubes are heated to forging temperature at one end, which is reduced by hammering or rolling for about 6 in. in length until it is practically solid. This reduced end is inserted through the drawing die and is gripped by a moving carriage, which in its turn is engaged with an endless chain of the draw bench and draws the tube through the die.

Cold drawing can be divided into three methods, known as plug drawing, bar or mandrel drawing, and sinking. In plug drawing the tubes are drawn through a die and over a plug which is held in its correct position by a long bar attached to the back of the draw bench. In this process, both outside and inside diameters of the tubes and the wall thickness are reduced.

In bar or mandrel drawing the tubes are threaded on to long mandrels and are then drawn through the die. After they have passed through the die, the tubes are tight on the mandrels, and to loosen them they are fed through a reeling machine, which slightly expands the tubes, thus allowing the mandrels to be withdrawn. This process permits the inside dimensions to remain the same and the outside diameters and wall thickness to be reduced. A somewhat brighter finish can also be obtained than with plug-drawn tubes.

Sinking is a term used for drawing tubes through a die only, with no internal tool. This is done when it is desired to reduce the outside and inside diameters but not the wall thickness.

In cold drawing, the reduction of area in each draw varies between 10 per cent. and 35 per cent., according to the type of steel being drawn, the low percentage being given to the high-tensile alloy steels and the high percentage to the low-carbon steels.

The process of cold drawing is much slower than hot work, because between each draw it is necessary to remove, by annealing, the work hardening caused by the previous draw. After annealing, the tubes are pickled in acid, usually sulphuric or hydrochloric, to remove scale, washed in water, dried, and then lubricated in a soap solution or a soap-oil emulsion, ready for the next draw.

Size Range.—The usual range of sizes of cold-drawn circular tubes is from $\frac{1}{8}$ in. to 6 in. diameter with wall thicknesses between one-quarter and one-seventieth of the diameter; but tubes are made outside this range. Cold-drawn tubes as large as 24 in. diameter have been specially produced. By the use of

special processes, tubes as small as 0·010 in. outside diameter by 0·004 in. inside diameter are made. A very wide range of non-circular tubes is also manufactured.

Types of Steel.—Cold-drawn seamless tubes are made in a great variety of steels. Straight carbon steels up to 1 per cent. carbon and many alloy steels, such as 3 per cent. nickel, chrome-molybdenum, carbon-chromium, chrome-vanadium, nickel-chromium, including the high-alloy stainless steels, are available; also free-cutting steels of the "leaded" type.

Condition.—These tubes can be supplied in various conditions to suit individual requirements. When ductility is required, they can be softened, the most up-to-date method being bright annealing, which leaves the surface clean and free from scale. If the tubes are to be used as stressed members, and without having to undergo much manipulation, they are usually supplied in the "as drawn" condition. A low-temperature heat treatment at about 400° C. can be given to "as drawn" tubes, if a higher yield-point is required. To withstand high stresses, tubes are supplied either air-hardened and tempered or oil-hardened and tempered, according to the type of steel used.

Mechanical Properties.—According to the composition, and the heat treatment given, tubes can be supplied having mechanical properties between 11 tons/sq. in. Yield, 20 tons/sq. in. Ultimate, and 90 tons/sq. in. Yield, 100 tons/sq. in. Ultimate.

The table below gives an indication of the mechanical properties obtainable:

Steel	*Condition*	*Tensile (tons per sq. in.)*		
		Yield	*Ultimate*	*Elongation 2 in.*
				Per cent.
Mild Carbon, 0·15% ..	As drawn	24	28	12
Mild Carbon, 0·15% ..	Softened	11	20	40
Carbon, 0·35%	As drawn	28	35	12
Carbon, 0·35%	Softened	16	26	35
Carbon, 0·50%	As drawn	38	45	10
Carbon, 0·50%	Softened	22	33	30
Carbon, 0·50%	Hardened	75	80	8
Chrome-molybdenum:				
Carbon, 0·3%	As drawn	38	45	12
Chromium, 1%	Softened	20	30	30
Molybdenum, 0·20% ..	Normalised	40	50	12
Nickel-chromium:	Hardened	60	70	10
Carbon, 0·25%				
Chromium, 1%	Softened	38	50	20
Nickel, 4%	Air-hardened	75	85/110	5
Stainless Iron:				
Chromium, 12% ..	As drawn	28	33	12
Carbon, 0·10%	Softened	16	26	35
Stainless Steel:	Hardened	50	70	10
Carbon, 0·10%				
Chromium, 18% ..	As drawn	45	50	15
Nickel, 8%	Softened	15	40	50

If tubes are to be brazed or welded, consideration should be given to the strength required in the structure, and to the effect of the heat applied during brazing or welding upon the steel.

If brazing is done, the heat applied will be a little over the normalising temperature, therefore practically any steel can be used, and the strength of the joint will vary between the air-hardened properties, at the actual joint, and the softened properties, at a short distance from the joint, of the particular steel used.

If welding is done, the heat applied has to be high enough to melt the steel,

which will cause intense hardness and brittleness if the wrong types of steel are used. For this reason, for complicated structures, the carbon content is limited to 0·26 per cent. maximum in both straight carbon and alloy steels, but this carbon content can be increased to 0·35 per cent. for fairly simple structures.

The recommended steels for welding are (1) straight carbon for relatively low strengths, (2) carbon manganese for medium strengths of the order of 20 tons/sq. in. Yield and 25 tons/sq. in. Ultimate after welding, and (3) chrome-molybdenum for high strengths of approximately 35 tons/sq. in. Yield and 40 tons/sq. in. Ultimate after welding.

Uses.—It is practically impossible to list all the uses to which cold-drawn seamless tubes are put, but a few examples of special applications are: small stainless, high-tensile tubes for hypodermic needles; tapered-diameter thin-walled alloy tubes, oil-hardened and tempered to approximately 90 tons/sq. in. for golf shafts and fishing rods: thin-walled tubes in alloy steel, supplied softened for coiling and for subsequent hardening and tempering for Bourdon coils; tubes with small bores and thick walls made in steels suitable to withstand high internal pressures at elevated temperatures; stainless-steel tubes for food handling.

In the tables on the next page, as the areas marked off are small, the inertia of these areas about their own centroids parallel to the axis under consideration, is neglected. To obtain the maximum value of section for bending couples the principal axis of section must first be found.

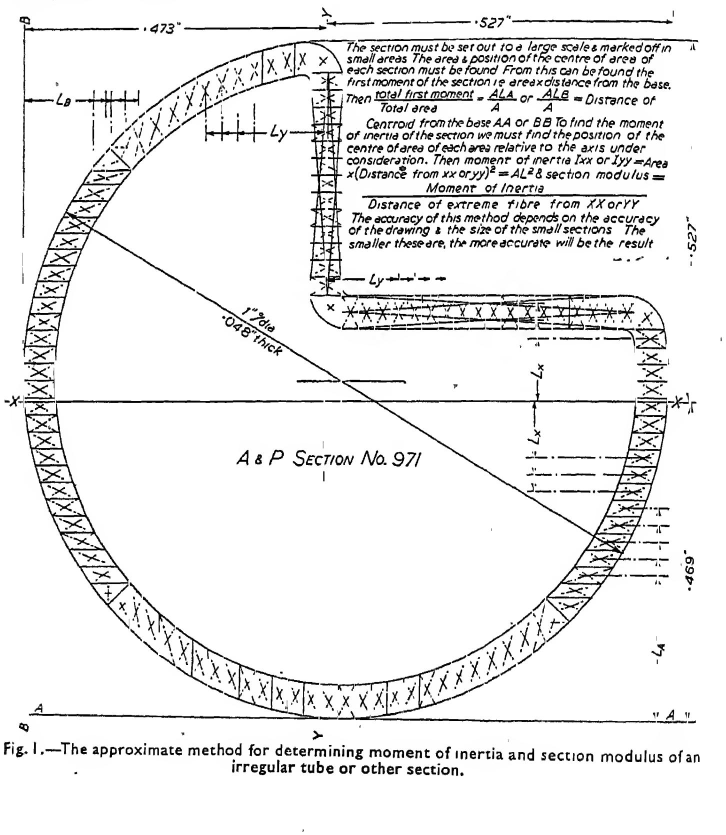


Fig. 1.—The approximate method for determining moment of inertia and section modulus of an irregular tube or other section.

Area	L_A	AL_A	Lx	ALx^2
·0012 × 2	·024	·0000576	·445	·000475
·0012 × 2	·026	·0000625	·443	·000470
·0012 × 2	·029	·0000696	·440	·000465
·00121 × 2	·032	·0000775	·437	·000462
·00125 × 2	·039	·0000976	·430	·000462
·00127 × 2	·045	·0001140	·424	·000456
·00129 × 2	·053	·000137	·416	·000446
·00133 × 2	·064	·000170	·405	·000436
·00136 × 2	·075	·000204	·394	·000422
·0014 × 2	·088	·000246	·381	·000406
·00144 × 2	·104	·000300	·365	·000383
·00151 × 2	·122	·000368	·347	·000363
·0012 × 2	·138	·000331	·331	·000263
·00115 × 2	·147	·000338	·322	·000238
·00115 × 2	·169	·000389	·300	·000207
·0012 × 2	·191	·000458	·278	·000185
·00151 × 2	·212	·000640	·257	·000200
·00144 × 2	·238	·000686	·231	·000153
·0014 × 2	·263	·000736	·206	·000119
·00136 × 2	·288	·000784	·181	·000089
·00133 × 2	·313	·000832	·156	·000065
·00129 × 2	·338	·000872	·131	·000044
·00127 × 2	·363	·000921	·106	·000029
·00125 × 2	·388	·000971	·081	·000016
·00121 × 2	·413	·001000	·056	·000008
·0012 × 2	·438	·001050	·031	·000002
·0012 × 2	·463	·001110	·006	—
·0012 × 2	·488	·001170	·019	·000001
·0012	·513	·000616	·044	·000005
·0012	·538	·000645	·069	·000006
·00125	·563	·000704	·094	·000011
·00125	·595	·000744	·126	·000020
·0108	·583	·006290	·114	·000140
·0108	·607	·006550	·138	·000206
·00125	·606	·000759	·137	·000024
·0012	·6375	·000765	·169	·000034
·0012	·6625	·000796	·194	·000045
·0012	·6875	·000826	·219	·000058

Area	I_A	AL_A	Lx	ALx^2
·0012	·7125	·000856	·244	·000071
·0012	·7375	·000886	·269	·000087
·0012	·7625	·000916	·294	·000104
·0012	·7875	·000946	·319	·000122
·0012	·8125	·000976	·343	·000141
·0012	·8375	·001006	·369	·000163
·0012	·8625	·001036	·393	·000185
·0012	·8875	·001066	·419	·000211
·0012	·9125	·001096	·443	·000236
·0012	·9375	·001126	·469	·000264
·00125	·969	·001210	·500	·000313
·00125	·9695	·001212	·500	·000313
·00125	·966	·001170	·497	·000298
·00123	·961	·001180	·492	·000298
·00125	·954	·001191	·485	·000294
·00129	·945	·001220	·476	·000292
·00131	·935	·001225	·466	·000284
·00134	·924	·001237	·455	·000271
·00137	·910	·001245	·441	·000267
·00141	·885	·001247	·416	·000244
·00147	·877	·001274	·408	·000245
·00117	·859	·001005	·390	·000178
·00115	·852	·000980	·383	·000168
·00115	·829	·000954	·360	·000149
·00117	·809	·000947	·340	·000115
·00147	·787	·001155	·318	·000149
·00141	·762	·001072	·293	·000121
·00137	·737	·001010	·268	·000098
·00134	·712	·000955	·243	·000079
·00131	·687	·000901	·218	·000062
·00129	·662	·000855	·193	·000048
·00125	·637	·000796	·168	·000035
·00123	·612	·000753	·143	·000025
·00121	·587	·000710	·118	·000017
·0012	·562	·000675	·093	·0000105
·0012	·537	·000645	·068	·0000055
·0012	·512	·000614	·043	·000002
·14969		·0702448		·013478

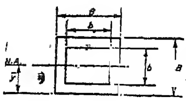
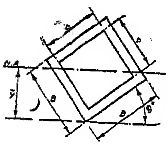
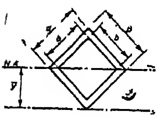
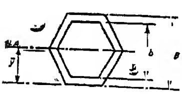
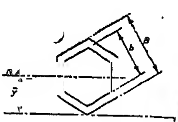
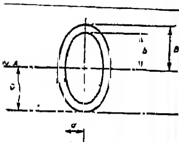
$$\frac{AL_A}{\text{Area}} = \frac{\cdot 0702448}{\cdot 14969} = \cdot 469'' \qquad I_{xx} = \cdot 013478 \text{ inches}^4 \qquad Z_{xx} = \frac{\cdot 013478}{\cdot 527} = \cdot 0256 \text{ inches}^3$$

Area	L_B	AL_B	Ly	ALy^2
·0012 × 2	·024	·0000576	·449	·000484
·0012 × 2	·026	·0000625	·447	·000478
·0012 × 2	·029	·0000696	·444	·000473
·00121 × 2	·032	·0000775	·441	·000471
·00125 × 2	·039	·0000976	·434	·000471
·00127 × 2	·045	·000114	·428	·000465
·00129 × 2	·053	·000137	·420	·000455
·00133 × 2	·064	·000170	·409	·000445
·00136 × 2	·075	·000204	·398	·000431
·0014 × 2	·088	·000246	·385	·000415
·00144 × 2	·104	·000300	·369	·000392
·00151 × 2	·122	·000368	·351	·000372
·0012 × 2	·138	·000331	·335	·000269
·00115 × 2	·147	·000338	·326	·000244
·00115 × 2	·169	·000389	·304	·000212
·0012 × 2	·191	·000458	·282	·000191
·00151 × 2	·212	·000640	·261	·000206
·00144 × 2	·238	·000686	·235	·000159
·0014 × 2	·263	·000736	·210	·000123
·00136 × 2	·288	·000784	·185	·000093
·00133 × 2	·313	·000832	·160	·000068
·00129 × 2	·338	·000872	·135	·000047
·00127 × 2	·363	·000921	·110	·000031
·00125 × 2	·388	·000971	·085	·000018
·00121 × 2	·413	·001000	·060	·000009
·0012 × 2	·438	·001050	·035	·000003
·0012	·463	·000557	·010	—
·0012	·488	·000588	·015	—
·0012	·513	·000616	·040	·000002
·0012	·538	·000645	·065	·000005
·0012	·563	·000675	·090	·000010
·00121	·588	·000707	·115	·000016
·00125	·613	·000765	·140	·000024
·00127	·638	·000808	·165	·000035
·00129	·663	·000854	·190	·000047
·00133	·688	·000914	·215	·000062
·00136	·713	·000968	·240	·000078
·0014	·738	·001031	·265	·000098
·00144	·763	·001095	·290	·000121
·00151	·788	·001185	·315	·000150
·0012	·808	·000970	·335	·000135
·00115	·829	·000954	·356	·000145

Area	I_B	AL_B	Ly	ALy^2
·00115	·852	·000980	·379	·000165
·0012	·856	·001026	·383	·000176
·00151	·875	·001320	·402	·000244
·00144	·893	·001285	·420	·000254
·0014	·908	·001271	·435	·000265
·00136	·922	·001253	·449	·000274
·00133	·934	·001240	·461	·000283
·00129	·943	·001216	·470	·000284
·00127	·953	·001209	·480	·000293
·00125	·959	·001098	·486	·000295
·00121	·964	·001165	·491	·000292
·0012	·970	·001162	·497	·000296
·0012	·973	·001165	·500	·000300
·0012	·976	·001170	·503	·000303
·0012	·976	·001170	·503	·000303
·0012	·973	·001165	·500	·000300
·00125	·969	·001210	·496	·000307
·00125	·966	·001206	·493	·000304
·0012	·937	·001124	·464	·000258
·0012	·912	·001094	·439	·000231
·0012	·887	·001064	·414	·000205
·0012	·862	·001034	·389	·000181
·0012	·837	·001003	·364	·000159
·0012	·812	·000975	·339	·000138
·0012	·787	·000945	·314	·000118
·0012	·762	·000915	·289	·000103
·0012	·737	·000885	·264	·000083
·0012	·712	·000855	·239	·000069
·0012	·687	·000825	·214	·000055
·0012	·662	·000795	·189	·000043
·0012	·637	·000765	·164	·000032
·0012	·612	·000735	·139	·000023
·0012	·587	·000705	·114	·000016
·0012	·562	·000675	·089	·000009
·0012	·537	·000644	·064	·000005
·0012	·512	·000614	·039	·000002
·00125	·477	·000596	·004	—
·0078	·488	·003810	·015	·000002
·0078	·464	·003615	·009	·000002
·00125	·470	·000588	·003	—
		·0708158		·014632

$$\frac{AL_B}{\text{Area}} = \frac{\cdot 0708158}{\cdot 14969} = \cdot 473'' \qquad I_{yy} = \cdot 014632 \text{ inches}^4 \qquad Z_{yy} = \frac{\cdot 014632}{\cdot 527} = \cdot 0278 \text{ inches}^3$$

Moduli and Moments of Inertia of Tubes

Sections	$\bar{y}$	I	$Z = \frac{I}{y}$
Irregular Sections	See Fig. 1	See Fig. 1	See Fig. 1
	$\frac{B}{2}$	$\frac{B^4 - b^4}{12}$	$\frac{B^4 - b^4}{6B}$
	$\frac{B[\cos\theta + \sin\theta]}{2}$	$\frac{B^4 - b^4}{12}$	$\frac{B^4 - b^4}{6B[\cos\theta + \sin\theta]}$
	$\frac{B}{\sqrt{2}}$	$\frac{B^4 - b^4}{12}$	$\frac{\sqrt{2}[B^4 - b^4]}{12B}$
	$\frac{B}{2}$	$0{\cdot}060[B^4 - b^4]$	$\frac{0{\cdot}120[B^4 - b^4]}{B}$
	$0{\cdot}577B$	$0{\cdot}06[B^4 - b^4]$	$\frac{0{\cdot}104[B^4 - b^4]}{B}$
	B	$0{\cdot}7854[B^3D - b^3d]$	$\frac{0{\cdot}7854[B^3D - b^3d]}{B}$

Manipulation.—Manipulation is generally understood to cover all operations to tubes other than pure machining operation after the straight tubes have been made. Perhaps the most common of these is bending.

Bending.—The following methods are those most used for bending cold-drawn steel tube.

Bending the tubes around a former or in suitably machined tools without any internal filling or maudrel being used.

Bending tubes as above but with a mandrel located inside at the point of bending, the tube being drawn off the mandrel during the bending operation.

Bending tubes as above after they have been filled with a suitable low melting-point filler such as resin or with a spring of suitable size and section.

The first method is used when large radii are required or when severe distortion at the bent portion does not matter. As a guide, the smallest radius with a tube having a 8 : 1 diameter thickness ratio is approximately 4 diameters to the centre line.

With the second method much smaller radii can be made and the bent portion is only slightly distorted. The smallest radius by this method is : Radius $= \frac{D^2}{10T}$ for tubes having a D.T. ratio of less than 1 : 15. (D = outside diameter; T = thickness.)

The smallest radius in proportion to diameter and gauge can be made with the last method. A tube having a 8 : 1 diameter thickness ratio can be bent with a centre-line radius of 1¼ diameters. With a radius as small as this the wall thickness on the outside of the bend would reduce in thickness at the thinnest point about 25 per cent. of the original thickness.

The foregoing remarks apply to low-carbon steel tubes in the fully softened condition. With higher tensile or alloy steels the radii increase according to the material used.

Smaller radii than those given can be obtained by special technique, but in these cases each job has to be specially considered.

Tapering.—Several methods can be used for tapering tubes, two popular ones being rolling and rotary swaging. With rolling, two rolls are made having machined in their peripheries a groove which corresponds to the finished tapered tube required. The rolls are mounted one above the other and geared together so that the larger and smaller portions of the grooves come together respectively.

A tube is gradually fed into these rolls until it is rolled into the shape of the groove machined in the rolls. The length of the taper is controlled by the diameter of the rolls, but it is possible to use more than one set of rolls to continue the taper on a tube.

When a rotary swaging hammer is used a pair of dies suitably machined to the taper required are used. The tube is fed between the dies until it is swaged to the shape of the groove in the dies.

Other methods are spinning to shape or pressing the tube into a solid die which has the required shape machined in. With all these methods the thickness of the tube increases progressively towards the small end. The amount of this increase depends on the rate and length of taper.

Press Operations.—Under this heading many operations can be carried out on tubes such as bulging, reducing, piercing, slotting, tapering, flanging, flairing, belling, trapping, etc., also special operations can be carried out on the tubes, such as forming the rifling in gun barrels without machining.

Machining.—All the usual machining operations can be carried out on tubes, but owing to their chemical composition and manufacturing operations they are not so "free cutting" as many of the free-cutting steels supplied in bar form. It is always necessary to "lip" the cutting tools much more severely when machining tubes than is required for machining solids.

Welding, etc.—The types of steel most suitable for welding have already been dealt with. Brazing, S.I.F. bronzing, low- and high-temperature soldering can be carried out on tubes in the usual manner, but alloy steels are more susceptible to liquid-metal penetration than the plain carbon varieties.

CALCULATIONS FOR TUBULAR BEAMS AND CANTILEVERS

The examples used for these formulæ have been drawn from *Strength of Materials*, by Case.

The standard formulæ as used with beams and their different type of loadings are given on pp. 98 to 117. They are here applied to a tubular construction.

From the type of loading the maximum bending moment (M) is obtained. In the case shown in Fig. 1 :

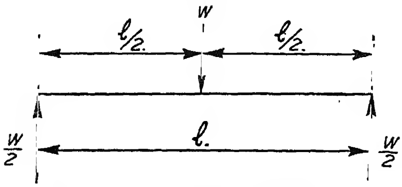


Fig. 1.—Loading diagram for straight tube.

$$M = \frac{Wl}{4} \qquad (1)$$

where W = load on material, l = length of beam.

When this valueis determined it has to be expressed in terms of the dimensions of the cross section and the intensity of stress produced, i.e. :

$$\frac{M}{I} = \frac{f}{y} \qquad (2)$$

$$M = fZ \qquad (3)$$

where I = inertia of section ; f = bending stress at height y from neutral axis (for circular tube taken as $\frac{D}{2}$) ; Z = modulus of section. Therefore, if M and f are determined, the size of tube to be used is determined by the value of Z.

$$\text{Maximum deflection (D) occurs at load } W = \frac{Wl^3}{48EI} \qquad (4)$$

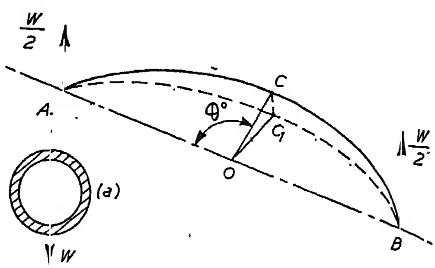
I is determined from formula (2).

E linear elastic modulus (Young's modulus).

In cases where the size of section is limited and it is required to know if a tubular section is strong enough for the job it is to perform, then the inertia of that section is the first value to be obtained.

Example of Curved Beam (ends built in horizontally).—Circular tube bend to a radius (a) of semicircle (Fig. 2b). Find deflection at (C) ; find torque at (C); find BM at (C).

Conditions : Weight at W is passing through centroid of section as when a curtain ring is passed over tube (Fig. 2a).

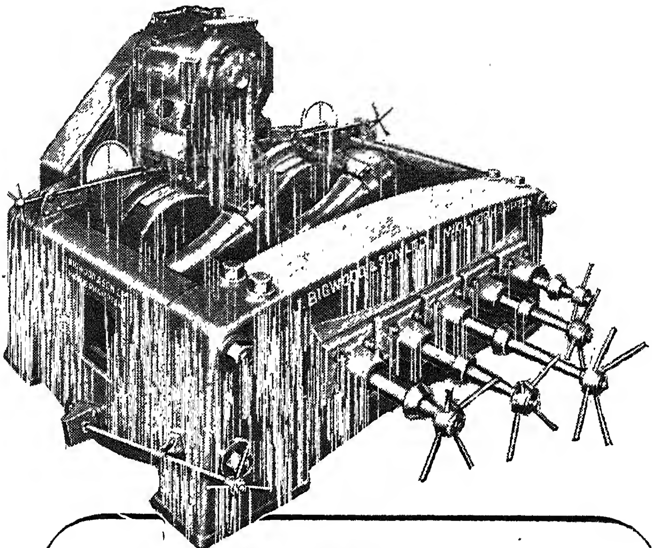


Figs. 2a and 2b.—Example of curved tubular beam.

$$D = \frac{a^3W}{2CK}(\cos\theta - \sin\theta + \theta - 1) + \frac{a^3W}{4}\left(\frac{1}{EI_1} + \frac{1}{CK}\right)\theta\sin\theta$$

$$- \frac{a^2Mo}{2}\left(\frac{1}{EI_1} + \frac{1}{CK}\right)(\sin\theta - \theta\cos\theta) \qquad (5)$$

where θ = Angle to the point of consideration $= \frac{\pi}{2}$.



W = Weight.

K = Torsion constant for a circular beam of tubing =

$$\pi t\left(2R^3 - 3R^2t + 2Rt^2 - \frac{t^3}{2}\right)$$

where R is external radius of tube.
t is thickness of tube.

I_1 = Inertia of section about diameter.
C = Modulus of rigidity.
E = Modulus of elasticity.
a = Radius of semicircle.

$Mo = \frac{aW}{\pi}$.

D is the deflection.

Bending Moment M is found from :

$$M = \frac{aW}{\pi}\sin\theta - \frac{aW}{2}\cos\theta \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Torque :

$$T = -\frac{aW}{\pi}\cos\theta - \frac{aW}{2}\sin\theta + \frac{aW}{2} \quad . \quad . \quad . \quad . \quad (7)$$

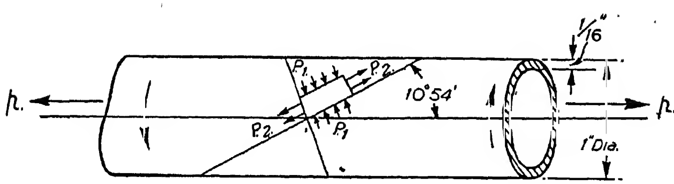


Fig. 3.—Calculating stresses at any point of tube. In this example the tube is subject to an axial pull of 1 ton, and axial torque of 0·094 tons/in.

Circular Tubes in Torsion

The shear stress (q) due to torque only is obtained from the formula :

$$\frac{q}{\frac{D}{2}} = \frac{T}{J} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

D = Outside diameter.
T = Torque in lb. or tons/in.
J = Polar moment of inertia of cross section.
J = $I_{xx} + I_{yy}$.

Angle of Twist in Thick Tubes due to Torsion.—Angle which tube is turned through is found from the formula :

$$\theta = \frac{TL}{CJ} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where θ = Angle of twist radians.
L = Length of tube in inches over which twist is measured.
J = Polar moment of inertia of tube.
C = Modulus of rigidity lb./sq. in.

Angle of Twist in Thin-walled Tubes due to Torsion :

$$\theta = \frac{TSL}{4CtA^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9A)$$

where θ = Angle of twist (radians).
A = Area enclosed by tube.
S = Perimeter of tube.
t = Thickness of tube.

Angle of Twist for a Tapered Tube where D_1 and D_2 are the Tube End Diameters respectively :

$$\theta = \frac{2TL}{C\pi t}\left\{\frac{D_1 + D_2}{D_1^2 D_2^2}\right\} \quad . \quad . \quad . \quad . \quad (9B)$$

Principal Stresses at any point of a Tube under Axial Load and Axial Torque :

Example: Tube Fig. 3 is subject to axial pull of 1 ton and axial torque of 0·094 tons/in. Find magnitude and direction of principal stresses at any point (i.e. neglect variation in shear stress from inside to outside of tube).

Let q = Mean shear stress due to torsion (tons/in.^{2}).
r = Mean radius of tube = $\frac{15}{32}$ in.
t = The thickness of tube = $\frac{1}{16}$ in.

Then the moment of total resistance to shear $= 2\pi r^2 qt = \dfrac{225\pi q}{8192}$ tons/in.

$$\frac{225\pi q}{8192} = 0{\cdot}094. \quad \therefore q = \frac{0{\cdot}094 \times 8192}{225\pi}.$$

$$q = 1{\cdot}09 \text{ tons/sq. in.}$$

Area of the cross section approximately $= 2\pi rt = \dfrac{15\pi}{256}$ in.^{2}

Hence the tensile strength $= \dfrac{1 \text{ ton}}{\frac{15\pi}{256}} = \dfrac{256}{15\pi} = p = 5{\cdot}45$ tons/in.^{2}

The principal stresses are : $\left\{p \pm \sqrt{p^2 + 4q^2}\right\} \quad . \quad . \quad (10$

$$= \tfrac{1}{2}\left\{5{\cdot}45 \pm \sqrt{29{\cdot}7 + 4{\cdot}75}\right\}$$

$$= \tfrac{1}{2}\left\{5{\cdot}45 \pm 5{\cdot}87\right\}$$

$$p = -\ 0{\cdot}21 \text{ tons/in.}^2 \qquad p_2 = 5{\cdot}66 \text{ tons/in.}^2$$

the positive sign denoting tension.

The planes across which they act make angles θ and $\theta + \frac{\pi}{2}$ with the axis, where

$$\tan 2\theta = \frac{2q}{p} = \frac{2{\cdot}18}{5{\cdot}45} = 0{\cdot}4 = 10° \ 54'.$$

Maximum Shear Stress

The maximum intensity of shear stress is obtained from the formula:

$$\tfrac{1}{2}\sqrt{p^2 + 4q^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

and is inclined at an angle of 45 degrees to the principal planes. This formula should be used as a criterion of failure when dealing with unlike principal stresses.

Combined Bending and Torsion.—The equivalent twisting moment on a tube is found from formula :

$$T = \sqrt{M^2 + T^2} \quad . \quad . \quad . \quad (12) \text{ (Based on Shear Stress Theory.)}$$

$$\text{or } T = \sqrt{\frac{2m}{m+1}M^2 + T^2} \quad . \quad . \quad (12A) \text{ (Based on the Strain Energy Theory.)}$$

where $\frac{1}{m}$ = Poisson's ratio.
M = Bending moment.
T = Pure torque.

Formulæ (12) and (12A) are used on plough axles, etc

Internal Pressures in Tubes.—Two principal stresses :

$$\text{Hoop stress : } p_1 = \frac{Pr}{t} \quad . \quad . \quad (13)$$

$$\text{Longitudinal stress : } p_2 = \frac{Pr}{2t} \quad . \quad (14)$$

where p_2 = Longitudinal stress.
p_1 = Hoop stress.
r = Internal radius.
t = Thickness.
P = Internal pressure.

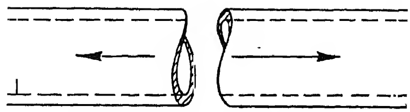


Fig. 4.—Internal pressures in tubes.

Longitudinal Stress.—The stress created in a tube by internal pressure on the ends. The mode of failure is as sketch Fig. 4.

Hoop Stress.—The stress in a tube under pressure acting tangential to the perimeter of a transverse section. The mode of failure is as sketch Fig. 5.

Radial Pressure.—The third principal stress which occurs in a tube under internal pressure in addition to p_1 and p_2 (Nos. 13 and 14) is a radial pressure which varies from p inside the shell to atmospheric pressure outside. In *thin tubes* this is neglected.

Thin Tubes—Internal Pressure

For calculating purposes of the strength of tubes let f denote the yield-point of the material, then for :

Thin Tubes.—A tube may be regarded as a thin cylinder when the thickness of the walls is less than $\frac{1}{46}$ of the outside diameter.

According to the Maximum Stress Theory. Hoop Stress Failure :

$$P = \frac{t}{r} f \quad . \quad . \quad . \quad . \quad (15$$

where P = The internal fluid pressure.
t = The thickness.
r = The internal radius.

According to the Strain Energy Theory :

$$P = \frac{t}{r} f \sqrt{\frac{4m}{5m-4}} \quad . \quad . \quad (16)$$

where $\frac{1}{M}$ = Poisson's ratio.

For steel take $m = \frac{10}{3}$.

The formula (15) is mostly used. The mode of failure being as shown in Fig. 4.

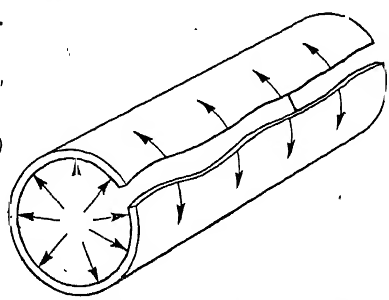


Fig. 5.—Internal pressures in thin tubes

Longitudinal Stress Failure

According to the Maximum Stress Theory :

$$P = \frac{2t}{r} f \quad . \quad . \quad . \quad . \quad . \quad (17)$$

According to the Maximum Strain Energy Theory:

$$P = \frac{2t}{r} f \sqrt{\frac{m}{2(m-1)}} \quad . \quad . \quad . \quad . \quad (18)$$

Thick Tubes—Internal Pressure (Neglecting Longitudinal Stress)

The two principal stresses are: (1) radial compressive stress (px), (2) hoop tensile stress (py).

Let f = the elastic limit of the material in simple tension. The failures of these tubes will be:

According to the Maximum Principal Stress Theory, when $py = f$:

$$\frac{P}{f} = \frac{k^2 - 1}{k^2 + 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

where P = Internal pressure per unit area.

k = Ratio of $\frac{R_2}{R_1}$.

R_1 = Inside radius.

R_2 = Outside radius.

According to the Maximum Shear Stress Theory (i.e. the elastic limit is reached when $px + py = f$):

$$\frac{P}{f} = \frac{k^2 - 1}{2k^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

According to the Maximum Strain Energy Theory:

$$px^2 + py^2 + \frac{2}{m}\, px\, py = f^2$$

$$\text{which gives } \frac{P}{f} = \frac{k^2 - 1}{\sqrt{2\frac{m+1}{m}k^4 + 2\frac{m-1}{m}}} \quad . \quad . \quad (21)$$

For tubing in the "as drawn" condition Lame's formula (19) is used.

For tubing in the fully softened condition or for ductile materials Haigh's theory formula (21) is used.

The maximum permissible pressure calculated by using formula 20 is a lower value than that obtained by using formulæ (19) and (21).

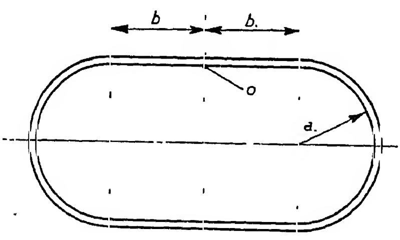


Fig. 6.—Internal pressures in flat-sided oval tubes.

Internal Pressures

Flat-sided Oval Tubes.—A straight tube, the cross section of which is shown in the diagram Fig. 6, is subject to an internal pressure P. The thickness is uniform and small compared with the dimensions a or b, and the effects of end constraints and of distortion of the cross section can be ignored.

Then the Bending Moment (M) at the point O per unit length of tube is given by:

$$M_O = Pb\,\frac{12a^2 + 3\pi ab + 2b^2}{6\pi a + 12b} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

Moment of resistance take unit length of tube, Fig. 7, say 1 in.

$$M_R = fZ \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

For tube to retain its equilibrium $M_O = M_R$.

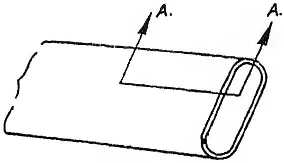


Fig. 7.—Moment of resistance.

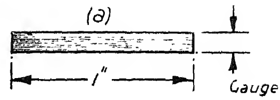


Fig. 7a.—Moment of equilibrium.

$$\therefore \mathrm{P} = \frac{fZ}{b} \cdot \frac{6\pi a + 12b}{12a^2 + 3\pi ab + 2b^2} \quad . \quad . \quad . \quad . \quad (24)$$

where f = Yield point of material.
P = Maximum pressure before any distortion of sides takes place.
$\mathrm{Z} = \frac{\mathrm{BD}^2}{6}$ (see Fig. 7a).

or $\frac{1 \text{ in.} \times (\text{gauge of material})^2}{6}$.

Thin Short Tubes under External Pressures

$$\mathrm{P} = \frac{\mathrm{E}t}{r}\left[(n^2 - 1)\frac{m^2}{12(m^2 - 1)}\left(\frac{t}{r}\right)^2 + \frac{\pi^4}{n^4(n^2 - 1)}\left(\frac{r}{l}\right)^4\right] \quad . \quad (25)$$

where P = Collapsing pressure.
r = The mean radius of the tube.
t = The thickness of the tube.
$\frac{l}{m}$ = Poisson's ratio.
n = The number of corrugations.
l = The free length of tube.

Where the ends of the tube are compelled to retain their circularity but are not otherwise restrained.

When the tube is very long compared with the diameter, we get:

$$\mathrm{P} = \frac{m^2\mathrm{E}t^3}{12(m^2 - 1)r^3}(n^2 - 1) \quad . \quad . \quad . \quad (26)$$

The smallest permissible value of n is 2, giving:

$$\mathrm{P} = \frac{m^2\mathrm{E}t^3}{4(m^2 - 1)r^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

in this case the section takes an elliptic form.

Note.—As the length decreases as covered by formula (25), the number of corrugations increases; i.e. when $n = 3$ collapse takes place at a lower pressure than $n = 2$. For shorter length still the collapsing pressure is given by taking $n = 4$. A good approximate value which constitutes a short tube is any length under (28) L = 6 × diameters.

Experimental values on both steel seamless and lap-welded long tubes have given collapsing pressures at:

$$\mathrm{P} = 50{,}000{,}000\left(\frac{t}{\mathrm{D}}\right)^3 \text{ lb./sq. in.}$$

where t = thickness; D = outside diameter in inches; P = external pressure.

Thick Tubes under External Pressure

Where $\frac{t}{\mathrm{D}}$ is greater than 0·03

t = thickness; D = diameter; P = external pressure.

$$\mathrm{P} = 95{,}520\,\frac{t}{d} - 2{,}090 \text{ lb./sq. in.} \quad . \quad . \quad (28)$$

Steel Tubular Struts.—The end thrust (P) that can be applied to a tubular strut is obtained from the following quadratic :

$$P^2\left(1 - 0\cdot26\,\frac{h\,yc}{k^2}\right) - P\left\{P_e\left(1 + \frac{h\,yc}{k^2}\right) + fS\right\} + fS\,P_e = 0. \quad . \quad (29)$$

On account of the researches carried on during the war in connection with struts for aeroplanes, the position is more satisfactory. Research shows that with ordinarily well-manufactured solid-drawn steel tubes the equivalent eccentricity of load due to initial crookedness or eccentricity of bore is very unlikely to exceed a value given by :

$$h = \frac{\text{length}}{600} + \frac{\text{diameter}}{40} \quad . \quad . \quad . \quad . \quad . \quad (30)$$

where diameter = internal diameter.

Therefore we use formula (29) with considerable confidence, putting

$$\frac{h\,yc}{k^2} = \frac{1}{5}\left(1 + \frac{1}{60}\,\frac{l}{k}\right) \quad . \quad . \quad . \quad (31)$$

where f = Maximum permissible compressive stress.

S = Area of cross section of tube.

$P_e = \dfrac{\pi^2 EI}{l^2}$.

k = The least radius of gyration.

h in formula (30) is the distance from the axis to thrust P.

Note.—In designing steel tubular struts attention must be paid to two important points—crinkling and heat treatment. The yield-point may be considerably reduced by any heat treatment which it receives, such as welding or brazing. On this account precautions should be taken to prevent such treatment, or the strengths must be taken as that of the annealed material.

Crinkling of Tubes.—When a tubular strut is under compression the tube may "crinkle," i.e. the walls of the tube may cave in and form folds, after the manner of a concertina. These folds may be circular, oval, or polygonal, and they occur after or before the longitudinal stress reaches the yield-point.

A formula by R. V. Southwell, which is only useful when $\frac{t}{R}$ is less than about 1/400, is :

$$P = E\,\frac{t}{R}\sqrt{\frac{m^2}{3\,(m^2 - 1)}} \quad . \quad . \quad . \quad (32)$$

P = The stress causing collapse ; R = Mean radius of tube ;

t = The thickness of tube ; $\frac{l}{m}$ = Poisson's ratio.

As approximate values :

(I) For tubes of mild steel having a yield in compression of 22 tons/sq. in. the strength depends on the Y.P. and not on the wrinkling stress, provided that $\frac{t}{R} < 0\cdot022$.

(II) For short specimens of thin tubes failure will occur at the yield or at a stress which is some fraction varying from 0·4 to 0·6 of the value obtained in formula (32).

(III) For tubes having $\frac{t}{R}$ greater than the value determined by (II) yield precedes wrinkling.

(IV) As an estimate of the strength of a tubular strut use formula (29), inserting in place of f the lower of the two values (i.e. yield or an appropriate fraction of the Southwell value). To avoid elastic instability as a primary cause of failure, the value of $\frac{t}{R}$ for steel tubes should be greater than 0·4 × Southwell's value of P.

Temperature Stresses.—The strength at high temperatures is apt to be misleading. It is well known that tensile tests at high temperatures, taken when the duration of the test is short, give higher results than when the load is applied over a long period. In other words, the figures obtained in short-time tests are of little value to the engineer, for material will ultimately fail (due to what is known as the "creep effect") at stresses far below these values Consequently, the most

important mechanical property of the heat-resisting steels is the "limiting creep stress"—which is the stress a material will stand at any given temperature without causing distortion or fracture even after unlimited service.

The following values have been obtained for Austenitic Steel:

Material	*Tensile at 700° C.*	*Limiting Creep Stress* $\frac{1}{1,000,000}$ *in./in./hr.* At 500° C.	*Limiting Creep Stress* $\frac{1}{1,000,000}$ *in./in./hr.* At 700° C.
	tons/sq. in.	tons/sq. in.	tons/sq. in.
Mild steel	7	3½	—
18/8/1/1	17	11	1½
20/25 Cr . . . . } 20/25 Ni . . . . }	20	14	1½

WEIGHT PER FOOT OF COPPER TUBES (Calculated on basis of 555 lb. per cu. ft.)

I.S.W.G.		11	12	13	14	15	16	17	18	19	20
Int'nal Diam. in Inches	*in Mm.*	*Thickness of Copper — Weight in Lb.*									
⅛	3·2	0·34	0·29	0·24	0·20	0·17	0·15	0·12	0·10	0·08	0·07
¼	6·3	0·51	0·44	0·38	0·32	0·28	0·24	0·21	0·17	0·14	0·12
⅜	9·5	0·69	0·60	0·52	0·44	0·39	0·34	0·29	0·25	0·20	0·18
½	12·7	0·86	0·76	0·66	0·56	0·50	0·44	0·38	0·32	0·26	0·23
⅝	15·9	1·04	0·92	0·80	0·68	0·61	0·53	0·46	0·39	0·32	0·29
¾	19·0	1·21	1·07	0·94	0·80	0·72	0·63	0·55	0·46	0·38	0·34
⅞	22·2	1·39	1·23	1·08	0·92	0·82	0·73	0·63	0·54	0·44	0·40
1	25·4	1·57	1·39	1·21	1·04	0·93	0·82	0·71	0·61	0·50	0·45
1⅛	28·6	1·74	1·55	1·35	1·17	1·04	0·92	0·80	0·68	0·56	0·51
1¼	31·7	1·92	1·70	1·49	1·29	1·15	1·02	0·88	0·75	0·62	0·56
1⅜	34·9	2·09	1·86	1·63	1·41	1·26	1·11	0·97	0·83	0·68	0·61
1½	38·1	2·27	2·02	1·77	1·53	1·37	1·21	1·05	0·90	0·74	0·67
1⅝	41·3	2·44	2·17	1·91	1·65	1·48	1·31	1·14	0·97	0·81	0·72
1¾	44·4	2·62	2·33	2·05	1·77	1·59	1·40	1·22	1·04	0·87	0·78
1⅞	47·6	2·79	2·49	2·19	1·89	1·70	1·50	1·31	1·12	0·93	0·83
2	50·8	2·97	2·65	2·33	2·01	1·80	1·60	1·39	1·19	0·99	0·89
2⅛	54·0	3·14	2·80	2·47	2·13	1·91	1·69	1·48	1·26	1·05	0·94

WEIGHT PER FOOT OF COPPER RODS (Calculated on basis of 558 lb. per cu. ft.)

Dia. In.	*Round Rods, Lb.*	*Square Rods, Lb.*	*Dia. In.*	*Round Rods, Lb.*	*Square Rods, Lb.*
⅛	0·048	0·061	1¼	4·76	6·06
3/16	0·108	0·136	1⅜	5·76	7·33
¼	0·190	0·243	1½	6·87	8·72
5/16	0·300	0·380	1⅝	8·04	10·23
⅜	0·430	0·545	1¾	9·35	11·87
7/16	0·585	0·742	1⅞	10·70	13·62
½	0·760	0·970	2	12·20	15·50
9/16	0·960	1·23	2¼	15·40	19·62
⅝	1·19	1·52	2½	19·02	24·22
11/16	1·44	1·83	2¾	23·02	29·31
¾	1·72	2·18	3	27·48	34·88
13/16	2·01	2·56	3¼	32·20	40·93
⅞	2·34	2·97	3½	37·35	47·47
15/16	2·68	3·40	3¾	42·90	54·50
1	3·05	3·88	4	48·80	60·12
1⅛	3·85	4·91			

POWDER METALLURGY

Products of powder metallurgy may be roughly divided into two classes. The first class would include those products which cannot be made at all by any other method, or at least cannot be made easily, except by powder metallurgy. In this class belong such products as refractory-metal wire and sheet, cemented-carbide tools, self-lubricating bearings, electrical-contact materials, etc. The second class would consist of those products which can be made by conventional methods, such as diecasting or machining of wrought or cast metal as well as by powder-metallurgy methods.

It is often possible in powder metallurgy to briquette and sinter a product to the finished size. In this way the cost of machining and the cost of scrap produced in machining are saved. In order to make the powder-metallurgy process competitive, these savings must be large enough to compensate for the increased cost of raw material, that is, powder versus bar stock or casting, and the cost of the powder-metallurgy-processing operations, namely briquetting, sintering, and sizing. In some cases, where only a semi-finished product can be briquetted, the cost of the final machining will have to be added to the powder-metallurgy operations in order to arrive at comparative costs. A complete comparison of costs, based upon the number of pieces to be produced, should also include the cost of tooling for briquetting and sizing, as against the tooling setup for machining by conventional methods. There are usually fewer operations in the powder-metallurgy process, but the cost of the hardened-steel tools needed for these operations is not low. Furthermore, it is of course necessary that the powder-metallurgy products have mechanical properties which will be satisfactory for the service for which they are intended.

Reference will be made particularly to those products which are manufactured from iron powder, and which therefore compete with products machined from steel bar stock, steel forgings, or steel or cast-iron castings. In the past many claims have been advanced with regard to the mechanical properties of such iron parts; and it has been felt throughout the industry that a clarification is necessary as to what mechanical properties can be obtained consistently in large-scale production.

Metal-Powder Specifications.—In articles made by powder metallurgy, the size and shape of the product has a direct bearing on its mechanical properties. The tensile strength, ductility, hardness, impact strength, etc., of a finished product machined from bar stock are assumed to be the same as those of the stock from which the piece was made. In castings, coupons can be cast together with the casting, the mechanical properties of these coupons can be determined, and in this way representative values for the mechanical properties of the casting can be obtained, although the influence of the section thickness may be quite important and will have to be taken into consideration. In powder-metallurgy products, the effect of size and shape of the finished product upon its mechanical properties is even more accentuated and will be discussed somewhat more in detail to show the reasons for it.

Mechanical Properties.—Metal-powder products are made by briquetting metal powders in steel dies and sintering the briquetted shapes in furnaces with controlled atmospheres. After sintering, the products may be further processed by a sizing operation or by sizing and subsequent resintering. The mechanical properties of the finished pieces may be described as depending upon four factors, as follows:

(1) Composition of the powder mixture.
(2) Grade of powders used.
(3) Temperature, length of time, and atmosphere of the sintering and resintering operations.
(4) Density, resulting from briquetting, sintering, and sizing operations.

The first three of these factors have parallels in cast and wrought materials (chemical composition, purity, heat treatment), but factor (4) is peculiar to metal-powder products. The density is also different from the other factors, because it

depends not only upon the processing of the product but also upon its size and shape. This correlation between density, processing conditions, size and shape of the product, and mechanical properties may be treated under the following headings:

(1) How the mechanical properties depend upon the density of the product.
(2) How the density depends upon the processing steps.
(3) How the density depends upon the size and shape of the product.
(4) How the size and shape of the product influence its processing.

(1) The tensile strength, impact strength, and hardness, as well as the ductility, of a metal-powder product will increase with increasing density of the product,

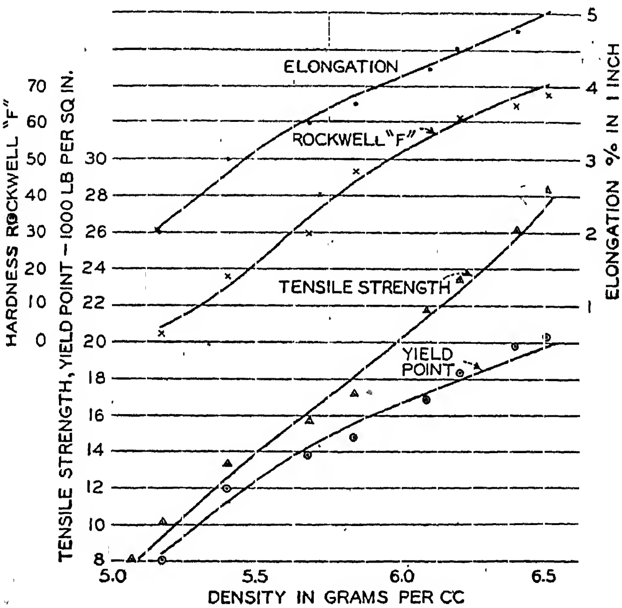


Fig. 1.—Relation of mechanical properties to density for test-pieces briquetted from a hydrogen-reduced iron powder and sintered 3 hr. at 2,000° F.

if the same powder mixture, quality of powder, and sintering treatment are used. Fig. 1, giving the tensile strength, yield-point, elongation in 1 in., and hardness for a number of test specimens made from a grade of hydrogen-reduced iron powder and sintered three hours in partially combusted natural gas at a temperature of 2000° F., but having different densities, illustrates the point.

(2) The density of a metal-powder product will depend to a certain extent upon the powder mixture, the quality of the powder, and the heat treatment of the product, but the most important factors influencing the density will be the briquetting pressure used to compact the powder into a coherent piece, and the sizing pressure used in coining or cold-forging the product after it has been sintered. A piece having a given size and shape will be the denser the higher the briquetting pressure and the higher the sizing pressure. Fig. 2 shows the correlation between briquetting pressure and density for the same set of specimens as shown in Fig. 1.

(3) The density of pieces having different shapes and dimensions will be different even if the same briquetting and sizing pressures are used. These differences are due to the fact that most metal-powder products are briquetted only along one axis. Therefore the friction between the die and the powder will influence the density in two ways:

(*a*) With a given briquetting and sizing pressure, pieces which are long and slender in the direction of pressing will be less dense than pieces which are short and thick (Fig. 3).

(*b*) Pieces whose ratio of length (dimension in the direction of pressing) to width (dimension perpendicular to direction of pressing) is large (in general greater than 2) will have an uneven density over their length. If pressed from

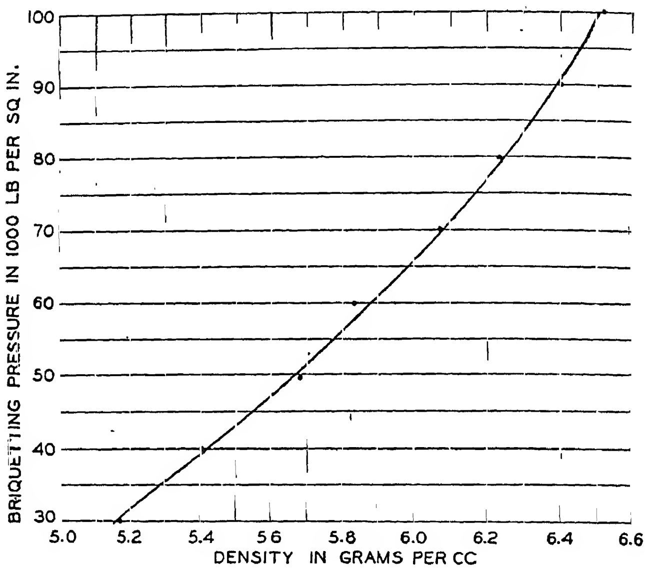


Fig. 2.—Relation of density to briquetting pressure for test-pieces briquetted from a hydrogen-reduced iron powder and sintered 3 hr. at 2,000° F.

both ends they will be denser at the ends than in the middle, and if pressed from only one end, they will be denser at one end than at the other (Fig. 4).

Pieces which have a non-uniform section in the direction of pressing (e.g. flanged pieces) may either be made with single punches or with multiple punches sliding relative to each other. If the piece is made with single punches the density will be higher in the short section than in the long section, because of the difference in the rate of compression of the powder. For some applications this difference in density and the corresponding difference in strength, ductility, and hardness is permissible; for other pieces multiple punches are necessary to make the density throughout the section as even as possible (Fig. 5).

(4) As explained, a high density may be obtained by using high briquetting and sizing pressures. However, these pressures are limited by the pressure which the briquetting and sizing dies will stand without rapid failure by fatigue or wear. The permissible sizing pressure and, to a lesser extent, the permissible

briquetting pressure will also depend upon the shape of the piece and the design of the die. A punch having a thin weblike section will not stand as high a pressure in pounds per square inch as a solid heavy section. For large pieces, the capacities of the available briquetting and sizing equipment may also be limiting factors. The density which can be obtained in complicated pieces will, therefore, not be as high as it is in standard test-pieces. In some cases, the lower physical properties, due to this lower density, may be compensated for by a change in the grade of powder or the sintering conditions, but such changes will of course also alter the cost picture.

Three Classes of Metal-Powder Products.—The foregoing reasoning makes it clear why it is not practicable to set up specifications for tensile strength, ductility, etc., to be determined on specially briquetted test specimens. The properties of such test specimens would not be representative of the properties of a complicated briquetted piece, even if the same briquetting pressure and sintering conditions were used. Neither is it usually possible to cut tensile or impact specimens from the metal products themselves, because most parts made from powders are too small for cutting test specimens. For this reason, it does not

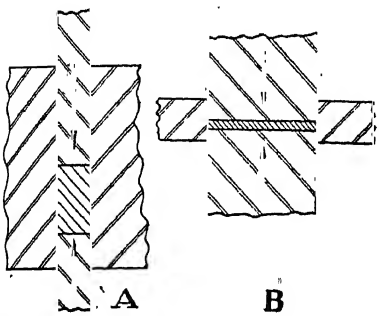


Fig. 3.—Schematic sketch illustrating lower density of long, slender piece A, as compared with short, thick piece B.

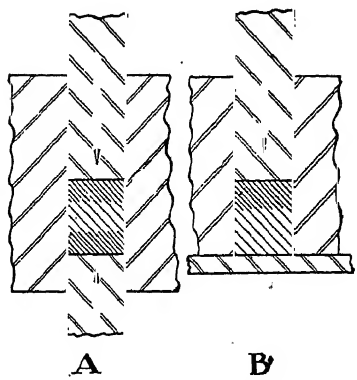


Fig. 4.—Schematic sketch illustrating uneven density distribution in pieces briquetted from both ends A and from one end B.

seem advisable to set up general specifications for the tensile properties of metal-powder products. The only specifications for iron parts in actual figures which should be included in a general specification are those for chemical composition and density. In order to grade parts made from iron powder, according to their properties, they may be divided into three types, as follows:

Type A: Materials having mechanical properties similar to common cast iron suitable for applications where the stresses are very low.

Type B: Materials similar to type A, having improved tensile strength, a definite yield-point, and a noticeable elongation.

Type C: Materials having mechanical properties approaching ordinary malleable iron, suitable for applications where stresses including impact are moderate.

There would be no sharp lines of demarcation between these various types, and the division into the three types would be for the convenience of the user rather than for any fundamental reasons. The grade of powder used, the briquetting and the sizing pressures, the time and temperature of heat treatment would determine in what class a particular product would fall, changes in one or more of these factors possibly shifting a product from one class to another. The three types would be identified by their specifications for chemical composition and for density, as suggested in Table 1. The table shows that for parts with better

TABLE 1.—CHEMICAL AND DENSITY REQUIREMENTS

Type	*Total Carbon, per cent.*	*Total Iron, per cent.*	*Density, g. per c.c.*
A	2·5 (max.)	95 (min.)	5·4 (min.)
B	0·4 (max.)	97·5 (min.)	5·8 (min.)
C	0·2 (max.)	98·5 (min.)	6·5 (min.)

physical properties, namely higher strength and ductility, an impure product with low density would not be suitable. The purity rises from 95 per cent. minimum iron to 98 per cent. minimum iron; the density from 5·4 g. per c.c. minimum to 6·5 g. per c.c. minimum.

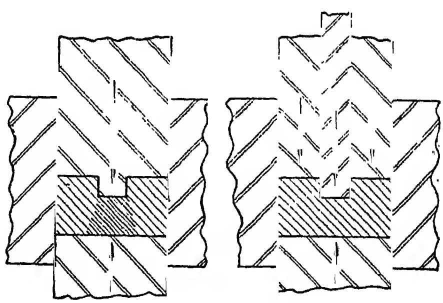
Type A would include parts which contain up to 2½ per cent. carbon. The carbon may be added to the powder mixture in the form of graphite and would combine with the iron during the sintering operation. Such carbon-containing iron-powder products are harder and stronger than straight iron products, but they are also more brittle.

Strength Tests for Individual Parts.—Because a general specification necessarily has to be broad, it will be necessary to develop detail specifications for individual parts. They should be set up after performance tests on the parts have shown that they are satisfactory for the application. The detail specifications should furnish a check on the uniformity of the production and, whenever possible, on the performance characteristics of the tested product. Such tests are as follows:

(1) Crushing, radial, or shear strength.

(2) Bending or impact drop test.

(3) Hardness at one or more specified points of the piece, or hardness variation over the entire piece.



A B

Fig. 5.—Schematic sketch illustrating uneven density distribution in a piece with non-uniform section when briquetted with a single punch A, as compared with the even density distribution in the same piece when briquetted with multiple punches B.

Static strength tests would be suitable for pieces where no particular impact resistance is needed; for instance, oil-pump gears may be so tested. The gear is held in a fixture and the load required to break off one of the teeth is determined. Hollow cylindrical pieces may be tested by a radial break test; the piece is crushed between two flat plates and the load is measured when failure occurs.

When a certain amount of shock resistance is required in a piece, a bending or an impact test should be devised. Tests have shown that impact strength and ductility in powder-metallurgy products parallel each other. In other words, a material which does not show any elongation in a tensile test, or no bending in a bend test, will usually be quite shock-sensitive. On the other hand, a material which has a fair amount of ductility will not break so easily under a sudden blow. Fig. 6 shows such a piece where shock resistance is required, and the testing fixture designed to test the piece. The piece is clamped in the vice in such a

way that one side of the slot is flush with the edge of the vice, with slightly more than one half of the piece protruding from the vice. The specification would read that a specified weight dropped from a specified height should not fracture

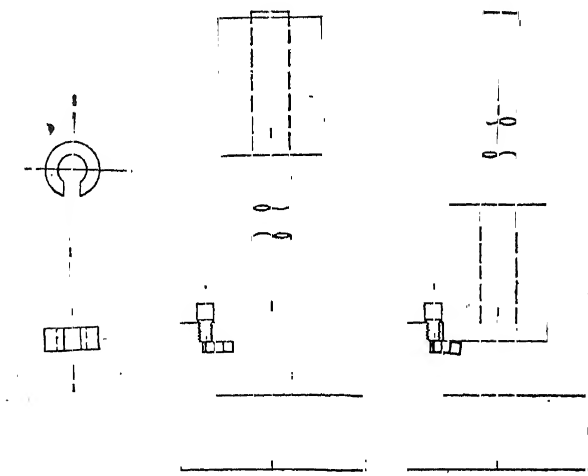


Fig. 6.—Piece which may be made by powder metallurgy, and a fixture designed to test its shock resistance.

the piece and that the same weight dropped from some lower height should not cause a crack in the piece.

Fig. 7 shows another specimen in which a certain amount of shock resistance is needed. This piece is briquetted with the long section in the direction of pressing, pressure being applied both from the top and the bottom. As previously explained, this piece will show some difference in density along the long section. It will have the lowest density and, therefore, the lowest strength and ductility in the middle of the long section. The test fixture is so designed that the piece is bent to a specified degree at this, its weakest point; the idea being that if the piece does not fracture at this point it will be satisfactory throughout. Simultaneously, the point where the flangelike section and the long section join is tested by bending the flangelike section. In this case, the actual piece is not expected to be bent in service, but it will have to withstand a certain amount of shock. As previously outlined, the bend test will also give a good indication of the resistance to shock of the piece.

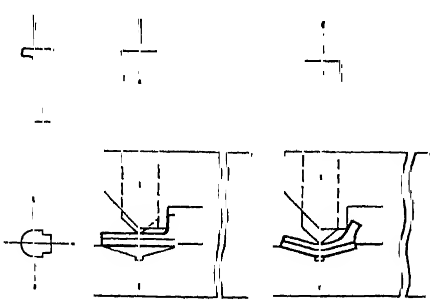


Fig. 7.—Piece which may be made by powder metallurgy, and a fixture designed to test its ductility.

Both the strength tests and the tests for shock resistance described are destructive tests and, therefore, only a small percentage of pieces can be tested. However, in many applications no non-destructive test would be satisfactory.

Hardness Testing.—A hardness test of the indentation type would be such a non-destructive test. Indentation-hardness tests, like Brinell or Rockwell, are very convenient and may be quite useful for powder-metallurgy products, but it is necessary that whoever specifies and applies the test understands the mechanism of an indentation test on porous material. The resistance to indentation, which is measured, is a function not only of the chemical composition and the microstructure of the tested piece but also of its density. The lower the density, or in other words the less material there is to resist the deformation, the further will the indenter sink into the material and the lower will be the reading. Two pieces which show identical hardness readings may therefore have entirely different properties. One may be low in combined carbon but high in density and therefore quite ductile and shock-resistant. The other may have a high combined carbon content but a low density, and would therefore be quite brittle and shock-sensitive.

The influence of density on the indentation-hardness reading must also be considered when the abrasion resistance of a material is to be evaluated. The abrasion resistance depends much more upon the microstructure of the material than upon its density. For instance, a piece made of iron powder and containing sufficient combined carbon may be heat-treated and may then be fully martensitic. Such a piece will be file-hard, but the hardness reading on the Rockwell C scale may be only 30. The peculiarities of the indentation-hardness test on powder-metallurgy products should always be kept in mind, and particularly so when the hardness of a product made from powder is compared with the hardness of a product made in the conventional way.

For the reasons just outlined, the tensile properties of products made from powder should not be included as part of a general specification; however, such properties can be and have been measured. The values shown in Table 2 were determined on special subsize specimens. Typical values are given for the three previously suggested types of material.

It must be admitted that the values given in Table 2, which are purposely on the conservative side, are not very impressive. Under laboratory conditions, it has been possible to obtain much superior properties and some such values have been widely publicised, but at the present time no large-scale production technique has been developed which would permit the manufacture of parts from iron powder with high strength and high ductility at a competitive cost. The main difficulty lies in achieving satisfactory ductility and impact resistance, while it is much less difficult to obtain higher strength and high hardness by proper heat treatment. These heat-treated materials are not specifically included in Table 2; they are rather brittle and cannot be used in any application where they have to withstand shock.

TABLE 2.—TENSILE PROPERTIES

Type	*Tensile Strength, psi*	*Elongation, per cent. in 1 in.*
A	15,000	½
B	25,000	3
C	35,000	7

Wide Application to Small Arms Parts.—There exist, however, numerous applications where the mechanical properties of iron-powder products are quite adequate for this purpose. Many of these components are at present made from low-carbon steel because that is the cheapest and most convenient material available. However, that does not mean that the physical properties actually needed are those of low-carbon steel. These are the applications where powder metallurgy is believed to have a field, if by this method a part can be made at a competitive cost and with a saving in machine time and in bar stock. The

metal-powder-parts manufacturer and the user of the parts should co-operate in selecting suitable applications and in setting up detail specifications which will ensure the quality and uniformity of production.

In the manufacture of bearings powder metallurgy is found of value, for bronze bearings are best made from porous metal, especially in cases where it is not possible to provide continuous lubrication. A successful bearing alloy must contain a mixture of hard and soft particles. In the case of porous bearings the hard particle or matrix is a 90/10 bronze, and the soft particle is a hole or pore. Thus a continuous lubricating film always exists over the whole surface of the bearing, even before rotation of the shaft commences. Some manufacturers add a small percentage of powdered graphite and others a small percentage of a lubricant to facilitate the pressing operation. High-speed mechanically operated presses of the eccentric cam-operated or rotary type are used for manufacture, and they provide for production up to 500 pieces per minute, as well as automatic feeds of the correct weight of powder, pressing, and automatic ejection.

Metal powders possess little ability to flow under pressure in a die. In a pressing of any depth it is usually desirable to press from both ends simultaneously, and this procedure is usually combined with a movable-core rod in the case of bushing dies. Upon ejection the parts must be heat treated or sintered.

By powder metallurgy articles can be made exactly to size and shape without machining. During sintering dimensional changes occur, either growth or shrinkage—generally the former—and the close control of these means a careful control over the quality of the powder, the composition of the mixture, the pressing operation, and the exact time and temperature cycle in sintering. After sintering, bearings made by this process are impregnated with lubricating oil, either 110° C. for 10 to 15 minutes, or at a lower temperature in a vacuum chamber. Finally, the bearings are sized to the necessary tolerances in a mechanically operated sizing press.

The familiar hard-metal carbide tool, such as Wimet, Ardaloy, Cutanit, Tecometal, etc., is made entirely by powder metallurgy. Although compositions vary to some extent, most of them consist of tungsten carbide with or without a proportion of titanium carbide, together with a proportion of binding or auxiliary metal (from 3 to 13 per cent.), which is usually cobalt, with or without proportion of nickel or iron. In America, tantalum carbide is being used to a considerable extent. Tungsten carbide can be melted and cast, but it is brittle and has little ability to withstand the shocks it will receive on use on a lathe. Powder metallurgy enables the hardness of the hard-metal particles to combine with the toughness of the bonding metal to produce a tool possessing the optimum qualities of both.

For a tungsten-carbide tool bonded with cobalt the powders involve preparation of pure tungsten oxide from the ore and reducing it in stages by heating in hydrogen until a pure tungsten powder of the right grain size is obtained. It is then mixed with carbon powder and heated in hydrogen in a carbon tube at approximately 1,500° C.

Iron and copper powders for use in powder metallurgy are produced by reduction of the oxide by use of hydrogen, coal gas, or by electrolysis. Tin, lead, and the light metal powders, such as aluminium powders, are produced by atomising. In preparing either the straight metal powder or the alloy powders, the purity of the metals and the shape of the metal particles should be carefully watched. Only clean surfaces of the metal particles will give a continuous cohesive surface in compression, thus assuring subsequent strength in the finished part.

The shape of the particles of metal powder should be angular, not globular, as globular powders do not compress well, though for certain applications, such as filters, globular powders may be used advantageously. Angular powders will deform under pressure, interlock, and give strength of cohesion to the compact sufficient to permit handling the compacted piece even before sintering. Where clean surfaces of the powder particles are assured, the heat created by pressure and friction is sufficient to create a molecular weld.

Metal powders are available of practically all known metals, but in addition a number of pre-alloyed powders, such as brass powder, bronze powder, and ferro-alloy powders, have been produced. Some of the age-hardening alloys, however,

are best created during the process of sintering. The age-hardened powders are generally too hard to compact easily, and even when they do the resulting part is generally brittle and of low physical properties. If the compact is formed from copper, aluminium, magnesium, or in the case of ferrous metals iron, nickel, or chrome, the metals can be annealed before compression and the softness of the powder allows excellent compression conditions. The alloys are then formed during the sintering operation.

It is important not to mix light and heavy metals, as they will tend to segregate and will not compact into a homogeneous mixture. Even if the mixing or blending of the different metals takes place immediately prior to their use, the mixing must continue from a few hours to twenty-four hours or longer to ensure absolutely even distribution. Pressures to form a compact vary from a few tons to 160 tons per sq. in. (about 25 tons per sq. cm.). By high pressure high physical properties are obtained in iron parts. The selection of what pressure is desired is governed entirely by the physicals expected in the finished part, how close such part is to come to the full density of the metal or alloy or how much porosity is expected.

A large application for the metal powders has been in making so-called oil-less or self-oiling bushings and bearings. Here porosities of 5, 10, and even 25 per cent. have been demanded, and the pressure varies according to the porosity expected.

Porosity does not depend entirely upon the shape of the particles or the pressure exerted, but can be created by mixing volatile salts, sawdust, etc., with the powders. During sintering these materials are volatilised, thus making spaces held by this material available for oil adsorption, and also creating channels which allow the compact to absorb oil through capillary attraction. After the compact has been compressed it is essential to sinter it. Sintering in air is rarely employed due to the danger of oxidation. Hydrogen is applied for most parts made from the more expensive metals. For everyday commercial operation, controlled atmosphere such as cracked ammonia or one of the controlled gases produced in special equipment is used. Optimum temperatures and periods of sintering for individual metals and compositions have been established by many tests.

One of the applications of powder metallurgy is in the manufacture of sintered carbides. Tunsten-carbide is one of the chief of these and it is obtained as a by-product from the manufacture of metallic tungsten, being derived from the slag resulting from this process. As an abrasive and as a material for tipping cutting tools it is finding increasing use in engineering.

The important characteristics of tungsten-carbide are its hardness and its compressive strength. Therefore, metal-cutting tools made of cemented or sintered carbides are now in general use in industry, chiefly because of the exceptionally high cutting speeds and long life which result from their use. They may be used for tools for cutting very hard materials or compositions which rapidly destroy other tools. It is the hardest metallic tool material known, the harder grades being about three times as hard as hardened tool steel, whilst one of the grades of cemented carbide has the highest compressive strength of any known material, approximately 890,000 lb. per sq. in. The sintered carbides are manufactured in a number of grades, and degrees of hardness and toughness, according to the material upon which they are to be used. Such carbides are now applied to various tools for turning, reaming, milling, etc.

CRACK DETECTION

The danger of the formation of cracks in vital or highly stressed parts has, of course, been appreciated since the earliest days of engineering. In the case of highly stressed automobile and aircraft parts in particular, a very critical standard is now maintained. Early methods of crack detection were necessarily simple, but sufficiently effective in most cases when employed by a skilled inspector. The ringing test, for instance, by which the note emitted by a part when tapped with a hammer gives an indication of its condition, is still employed during routine checking of the wheels of railway rolling stock. Similarly, if a steel component is suspended and tapped, it should give out a true note if in sound condition, whereas the note will sound " dead " if the part is cracked.

Again, visual detection of cracks can be carried out if the parts have a reasonably highly finished surface ; on public transport vehicles and on many racing cars one frequently sees vital parts, such as steering arms and front axle heads, highly polished to facilitate regular inspection of the parts for cracks. This principle was also used until fairly recently in aircraft production, an inspector often spending an hour or more examining a highly stressed engine component with a magnifying glass. Fine cracks, which may occur during grinding operations, may not ordinarily be visible, but can be detected on sample parts by etching the surface with acid.

Yet another widely used method of crack detection is to clean the suspected component thoroughly, and then to wipe it over with a rag soaked in paraffin or hot oil. The part is then cleaned off and painted with whitewash. As this dries, any oil or paraffin trapped in a crack will seep through and discolour the surface. This practice is still fairly widely followed when checking aircraft parts, such as undercarriage axles, for cracks during the examination of dismantled components for renewal of the certificate of airworthiness.

Time-saving Methods.—The effectiveness of the foregoing methods, however, will necessarily depend on a certain degree of skill on the part of the inspector, besides taking a considerable time if they are carried out efficiently. Consequently, the magnetic method of crack detection is now being widely adopted ; with the aid of suitable apparatus it is possible to inspect a component such as an automobile or aircraft crankshaft minutely for surface cracks or slag inclusions in a matter of five minutes, with the further assurance that the smallest cracks, which could not be detected by a powerful pocket magnifying glass, will immediately be revealed.

There are two methods of applying electro-magnetic principles to crack detection. The first consists of placing the component across the poles of an electro-magnet. No great strength of magnetic field is required, a magnetising field of about 20 ampere turns per inch usually being adequate for a closed magnetic circuit, while residual magnetism is frequently sufficient.

After removing the part from the magnetiser, it is painted with or immersed in a detecting ink, which carries finely divided particles of iron in suspension. If a crack is present, magnetic poles will be formed on each side, and the iron particles will line up and reveal the defect clearly. It therefore follows that it is important to place the component on the magnetiser so that the path of the magnetic flux is at right angles to the suspected crack. With larger components, such as crankshafts or camshafts, the detecting fluid is often poured on while the part is still between the poles of the magnetiser.

De-magnetising Test-pieces.—Since it is undesirable that any residual magnetism should remain in the part after inspection, a de-magnetiser must be employed before the part is put into service. This can be of the platen or aperture design according to the nature of the component, and is, of course, of the type already familiar to users of magnetic chucks.

The alternative method of magnetic crack detection is to produce the magnetic field in the part itself instead of employing an external field. A heavy alternating current is passed through the part, generally in the form of an impulse of very high current for a short duration, rather than a sustained current flow. This method of testing is particularly valuable in the case of long bars, although

it will only show up longitudinal cracks. De-magnetising, on the other hand, is unnecessary, since the only magnetism present is that which forms along a crack.

A Typical Detector.—An ingenious crack detector which combines both these principles is the Johnson-Fel detector. This detector, which is portable and can be used in any part of the factory or workshop where there is a suitable A.C. current supply, is now used by a large number of prominent manufacturers and has been supplied to the Air Ministry. In the first method the electric current is passed through the actual test-piece. In the case of bars or tubes cables of $\frac{3}{8}$ to $\frac{1}{2}$ sq. in. in area are fitted with suitable copper clamps to make contact with the ends of the test-piece. For intricate or heavy parts, such as crankshafts, it is possible to support the component on cast-iron V-blocks lined with brass or copper gauze, the V-blocks being connected to the machine by flexible cables.

When dealing with bars or tubes the clamps can be gradually moved along the bar until the whole length has been tested, while end faces of large-diameter bars can be examined by making contact at diametrically opposite points on the circumference. The length or diameter of the bar which can be dealt with at one operation depends on its composition and material. The harder the steel and the higher its carbon content, the greater the length or section that can be examined.

Testing Alloys.—The composition of the metal also affects the period during which the magnetic effect lasts. In the case of high-carbon steels, alloy steels, and hard steels, the effect may last three months or more; whereas with a very low carbon content the magnetising effect may last only six hours. Parts magnetised on the Johnson-Fel machine do not show any external field, however, unless a crack is present; when tested for residual magnetism sound parts, therefore, appear non-magnetic.

Smaller parts can be placed across the actual contacts of the machine, which are adjustable to deal with components of different shapes and size. Clamps can be used for irregularly shaped specimens or high-speed machine tools, while a lever head can be adopted to enable bolts or other repetition parts to be tested in quick succession. In order to ensure that satisfactory contact is made, a pilot lamp will glow only when the correct current is being passed, while a second pilot lamp indicates that the machine is correctly connected to the main supply.

The alternative application of the machine is obtained by passing the current through a copper or brass bar which is threaded through the actual test-piece. This provides the only really effective method of checking rings, gear wheels, pinions, ball races, gudgeon pins, or any other component with a hole through it, enabling examination for defects in all directions to be carried out in one operation. The part is simply threaded on to the bar of the jig, the switch is pressed, and the part removed for dipping, pouring, or spraying with detecting ink.

Fatigue and Grinding Cracks.—When parts which have already seen service are examined in a machine of this type, fatigue cracks may be detected; usually developing in the plane of maximum stress, and originating from a definite starting-point, such as a badly formed radius, a sharp edge, or a tool mark. In practice, however, an efficient magnetic crack detector will often show up cracks formed during the original grinding or hardening process, which must obviously have been present before the part was assembled into the engine or put into use. This has led to an increasing tendency to test parts—particularly those used in aero engines—before passing them to the stores or the assembly lines.

Grinding cracks are shown up by the magnetic detector in cluster or network form; they seldom penetrate very deeply into the outer skin of the material, but, nevertheless, may prove dangerous when the part is put into service. Naturally, it is usually necessary to judge each case on its merits. Cracks on gear teeth which run from the roots to the tips of the teeth, and which are not too close to the edge, may be passed, provided that the part is returned for further inspection after the engine has been assembled and tested. If the cracks run along the length of a tooth parallel to the root or tip, on the other hand, the pinion is rejected owing to the risk of the cracks extending under load.

It is seldom satisfactory to remove grinding cracks (which are usually caused by drastic grinding of a hardened material) by light stoning; in the case of gears the stoning operation is almost certain to alter the tooth form, while the

fact that the surface appears perfect after stoning does not indicate that the internal stresses which originally caused the cracks have been normalised.

Heat-treatment Cracks.—Hardening cracks are of a different nature from those caused by grinding, generally being isolated and penetrating to a much greater depth. They constitute a definite danger signal, since they often indicate the presence of small slag inclusions in the metal. In view of this, and the fact that they are almost certain to extend in use, the presence of hardening cracks results in the rejection of the part for aircraft work.

It will be obvious that a magnetic crack detector can prove extremely valuable in rejecting faulty components at a comparatively early stage in their manufacture, probably saving a considerable amount of expensive machining which would otherwise represent wasted time. Crack detectors are also being employed in modern factories to control the standard of bar material, stampings, and forgings coming into the works. In one aero-engine factory in which magnetic crack detection is applied to raw materials and parts during the early machining processes, the number of parts subsequently rejected before or after engine test has been reduced by 25 per cent.

Testing Parts in the Rough.—A development which is likely to influence this aspect still further is the fact that electro-magnetic crack detection is no longer limited solely to bright rolled bars or machined or ground surfaces. Rough stampings, black bar, or sealed parts after heat treatment have hitherto been tested at suspected points by polishing the metal locally. Special coloured detecting inks are now being introduced, however, which show up against a dark surface, with the result that the steel stamping or forging can be examined without preliminary polishing or machining. Satisfactory results have also been obtained on black-bar stock by applying a thin coat of aluminium paint to the bar, against which the normal detecting ink shows up clearly.

Non-ferrous Metals.—Whilst the magnetic system of crack detection is ideal for ferrous metals, it will not, of course, work on non-ferrous metals. It was not until recently that a system of crack detection for such metals was devised. Previously, anodising and the oil and chalk methods had been used, but they were not positive in their results. Both of these depend upon the assumption that the crack is filled with chromic acid or oil, which afterwards seeps out and stains the surface around the cracks.

Basically, all methods depend upon close visual examination under a light source which uniformly illuminates the flaw or crack and the article being inspected; this in turn involves skilled labour and a considerable amount of fatigue and eyestrain, with the consequent danger of faulty material being passed as perfect.

The use of ultra-violet light and fluorescent materials offers a new approach to the problem. A non-fluorescent material activated with ultra-violet light will appear black or purple, depending upon the nature of the material; a crack or flaw in the material if filled with a fluorescent filler will glow vividly with a characteristic colour, thus the flaw or crack is filled with light, while the remainder of the specimen remains dark.

The advantages of this method are too obvious to need enumeration.

The Glo-Crack System makes use most successfully of this phenomenon. The specimens, pressings, stampings, etc., to be examined are immersed for an automatically controlled period in a bath of fluorescent material at a temperature of 75° C. The specimens are withdrawn and then washed in a solution which removes all fluorescent material that has not become anchored to the edges of the flaws or cracks.

Examination under a black lamp (a source of ultra-violet light) immediately shows up any flaws or cracks. Surface scratches which only have a depth equal to or less than their width are not shown.

The total time taken to examine in this way a large specimen, such as a piston, does not exceed three minutes.

The Glo-Crack method is speedy and certain.

The Plant.—The plant is available in either the single-batch or tray type, or on very much larger scale, to keep pace with the requirements of the production line. The operation is entirely automatic, and the current consumption is only 1 kw.

The floor space occupied is small, but the throughput is such as to keep pace with any production line.

Labour can be trained within a few hours.

Technique.—The shape of the articles governs to some extent the technique employed ; for instance, the articles which can be loaded into trays and handled in batches can be best processed by dipping. Larger articles, such as airscrew blades, need a different technique. In general, the process can be adapted to deal with any articles, and has been successfully employed on specimens ranging from contact-breaker screws to aircraft petrol tanks.

The Fluorescent Solution.—The materials which are the core of the system are solvents which efficiently perform their primary function of maintaining the fluorescent material in solution, and of carrying it into the flaws or cracks. They also efficiently and thoroughly degrease any specimen immersed in them.

Cost of Processing.—The fluorescent-treatment loss is approximately 0·23 gal. per 1,000 sq. ft. of specimens, and the washing solution loss is approximately 0·17 gal. per 1,000 sq. ft. At the prices ruling to-day this works out at under one penny per square foot treated. In a continuous plant further economies can be effected by the addition of solvent recovery plant.

Advantages.—(1) Can be used with equal efficiency on ferrous or non-ferrous materials.

(2) Positive detection without eyestrain.

(3) Degreases the specimens, thus telescoping two operations.

(4) Can be used by unskilled labour.

(5) No staining of specimens.

(6) Specimens require no additional treatment, such as de-magnetising or cleaning.

(7) Extreme simplicity and cheapness.

The problem of accurate crack detection has assumed greater importance now that the new process of filling cracks and blow-holes with a plastic material under pressure has been introduced. This new process, allied to crack detection, means that practically every casting is usable, whether cracked or not. Formerly there was a high percentage of rejection of castings due to flaws which did not reveal themselves until a large amount of costly machining work had been undertaken.

Filling Porous Castings.—The new process makes use of a synthetic resin of the phenol-formaldehyde type in solution. It avoids the rejection of a casting in the final stages of production. The process consists in filling the casting with sealing solution, and then applying and maintaining the pressure equal to, but preferably greater than, the usual test pressure. This pressure can be applied by means of air or by a hydraulic pump. The resin solution can be cured in any of the standard ovens or furnaces capable of attaining a temperature of 150° C. Provision must, of course, be made to enable the solvents in the solution to disperse freely during the preliminary stage of baking.

The casting must first be free from moisture and grease and, if the castings have already been pressure-tested in water, it is essential that all moisture be removed by baking at a minimum temperature of 105° C. The apertures are then closed, as when pressure testing, but two or more are left open, one for connection to the pump, and the other for overflow to avoid airlocks.

The casting is now filled with the solution until it overflows from the outlet, which is then closed, and pressure built up and maintained for 10 to 30 minutes while the solution penetrates into the porous metal. The casting is drained and washed out with a special solvent supplied by the makers of the sealing solution. The final operation is to place the casting in an oven at room temperature and heat is gradually applied until, after an hour, 85° C. is reached. This temperature is maintained for a minimum of a further hour, and during this the solvents are eliminated. The baking treatment is concluded by raising the temperature during the next hour to about 150° C. and maintaining this for a further hour at least.

Most works have the plant for carrying out these operations. The use of these sealing solutions has been approved by the Ministry of Aircraft Production for slightly porous castings, but the prior approval of the main Contractor's Supervising Inspector must be obtained for the recovery by this process of particular types of porous castings.

DIECASTING

Diecasting is a modern process for the mass-production of large quantities of metal components. The advantages of diecasting are:

(1) Speed of manufacture.
(2) Good surface finish.
(3) Saving in machining.
(4) Saving in cost.
(5) Large range of size attainable.
(6) Possibility of reducing section to attain lightness.

TABLE I

No.	*Question*	*Gravity Process*	*Pressure Process*
1.	What is a suitable quantity?	500 upwards.	2,500 upwards.
2.	What weekly output can be attained, using a single-impression die?	*Weight* — *Weekly Output* 2 oz. — 1,000–2,000 $\frac{1}{2}$ lb. — 500–1,500 2 lb. — 300–1,000	*Weight* — *Weekly Output* 2 oz. — 3,000–8,000 $\frac{1}{2}$ lb. — 2,000–4,000 2 lb. — 500–3,000
3.	Can a multiple-impression die be used to increase output?	Occasionally, if the part is of suitable design. But it is rare that a die with more than two impressions can be used.	Frequently, if the part is of suitable design. Four-impression dies are often used and in special cases twelve or more impressions.
4.	What alloys are usually employed?	Zinc alloys Aluminium alloys Magnesium alloys Brass Aluminium-bronze (A greater range of alloys can be gravity cast than can be pressure cast.)	Zinc alloys Aluminium alloys (Sometimes magnesium-, tin-, and lead-base alloys. 60/40 brass can be pressure cast for suitable designs.)
5.	What accuracy is achieved?	Plus or minus 0·005 in. per in. (There may be evidence of the runner on a gravity diecasting and accuracy may be less at this point.)	Depends on melting-point of alloy. Plus or minus 0·0015 in. per in. for zinc alloys; 0·0025 in. per in. for aluminium alloys.
6.	What is a suitable minimum section?	$\frac{5}{64}$ in.–$\frac{5}{32}$ in.	$\frac{3}{64}$ in.–$\frac{3}{32}$ in.
7.	What is the minimum size of holes?	Depends on alloy: about $\frac{3}{16}$ in. for copper alloys, $\frac{1}{8}$ in. for aluminium alloys.	Depends on alloy: about $\frac{1}{32}$ in. for zinc alloys, $\frac{3}{32}$ in. for aluminium alloys.

Zinc-base alloys and aluminium-base alloys represent by far the greater part of the tonnage produced by the industry. Copper alloys and magnesium alloys are next in importance, and small quantities of tin- and lead-base alloys are diecast.

Two processes are in regular use:

(1) Gravity diecasting, where a manually operated die, of steel or cast iron, is used as a permanent mould for producing diecastings.

(2) Pressure diecasting, where the alloy, in a liquid or pasty condition, is injected under high pressure into a permanent mould, which is machined from steel die blocks and bears one or more impressions of the part to be produced. Recesses and holes are made by steel "cores," which are usually capable of being independently moved in or out of position and are inserted into the die cavity prior to casting and withdrawn from the casting immediately it has solidified. The die is mounted on a machine so that the two halves can be closed together ready for casting and drawn apart for the removal of the diecasting.

Table I shows some characteristic features of gravity and pressure diecasting, and is intended to help designers to choose which process is likely to be more suitable. It should be noted that the figures given in this and the subsequent tables are approximate and represent average cases.

Alloys for Diecasting.—The process is applied to alloys ranging from low melting-point tin alloys to high melting-point copper alloys (though the alloys of medium melting-point, namely zinc-base and aluminium-base alloys, are preponderant). The following alloys are diecast:

Tin alloys.
Lead alloys.
Zinc alloys.
Aluminium alloys.
Magnesium alloys.
Copper alloys.

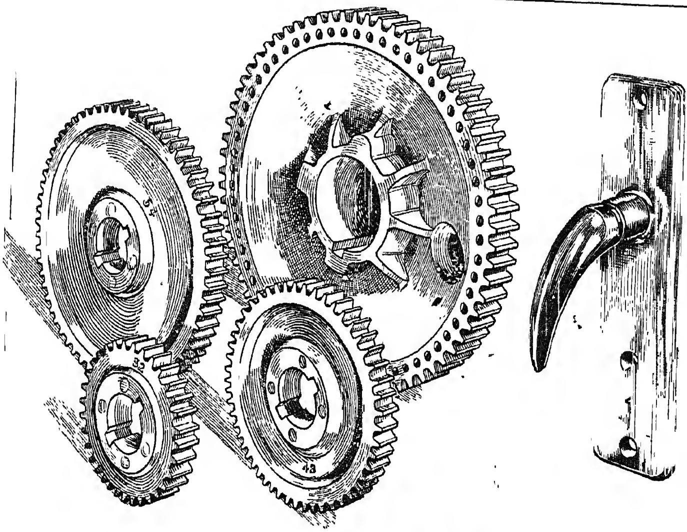
Zinc-base Alloys.—The modern zinc-base alloys in their diecast condition offer an excellent combination of good properties—good castability, low cost, accuracy and ease of machining (where this is necessary). The mechanical properties are considerably better than those of cast iron and practically as good as those of brass. By attention to design, it is possible to provide additional strength in positions where this is required, either by local increase of section or by the introduction of ribs.

To obtain optimum properties it is essential that the zinc alloy is of a very high standard of purity (see Table II). Impurities, such as tin, lead, and cadmium, must be rigorously excluded. In modern diecasting establishments meticulous care is taken that impurities are avoided, and thus the zinc-base alloys in their diecast form possess excellent and *permanent* mechanical properties.

The zinc alloys are used in peace-time for components of motor cars, electric motors, and switchgear, domestic appliances and fittings, machine tools, lawn mowers, and scientific instruments. Fig. 1 shows a typical peace-time application, and Fig. 2 illustrates lathe headstock and change-wheel gears which have been diecast in these alloys.

Aluminium-base Alloys.—(*a*) *Aluminium-silicon Alloy* (*L.33*): It has long been recognised that this is the most suitable aluminium alloy for pressure diecasting, and it is suitable also for gravity diecasting. Its composition is based on silicon 10–13 per cent., aluminium remainder. The alloy is not necessarily "modified" by additions of sodium, since the operation of diecasting into the metallic mould confers a modified structure on and near the surface, and mechanical properties characteristic of the modified alloy are obtained.

(*b*) *D.T.D.424* is the principal one of these, and though there has been controversy regarding its suitability, it is now reckoned quite satisfactory for a large range of propositions. The difficulties associated with it are generally overcome by adopting thicker gates and deeper vents than those used for L.33. Design of the casting plays an important rôle in avoiding cracks in this alloy—internal corners should not be sharp and generous radii are essential.



Figs. 1–4.—Some typical diecastings.

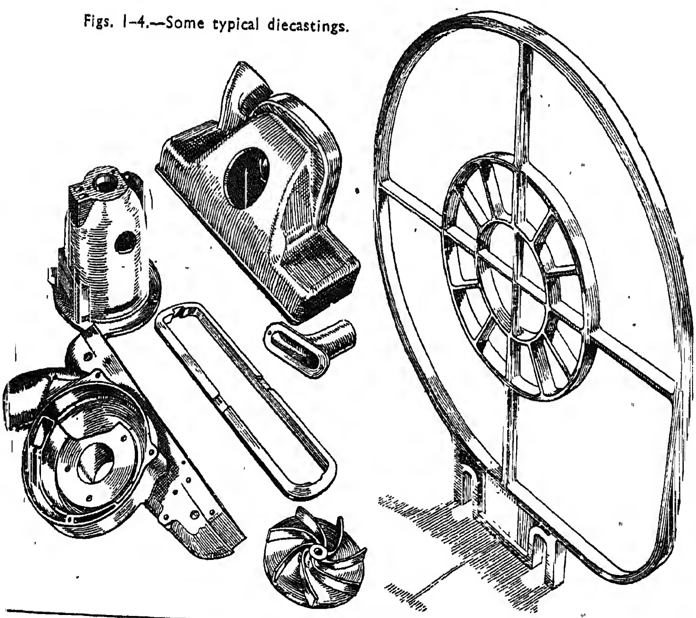


TABLE II

COMPOSITION AND PROPERTIES OF ZINC ALLOYS FOR DIECASTING

Properties and constants are as determined by the New Jersey Zinc Co.

		Mazak 2	*B.S. 1004(A)*	*B.S. 1004(B)*
		%	%	%
Composition by weight per cent.	Copper	2·5–3·5	0·10 max.	0·75–1·25
	Aluminium	3·5–4·5	3·5–4·3	3·5–4·3
	Magnesium	0·02–0·10	0·03–0·08	0·03–0·08
	Iron, max.	0·100	0·100	0·100
	Lead, max.	0·007	0·007	0·007
	Cadmium, max.	0·005	0·005	0·005
	Tin, max.	0·005	0·005	0·005
	Zinc (99·99+ per cent. purity)	remainder	remainder	remainder
Mechanical properties	Charpy impact strength, ft./lb., ¼ × ¼-in. bar, as cast	20	* 20	* 20
	Charpy impact strength, ft./lb., ¼ × ¼-in. bar, after eight years indoor ageing	2	25	19
	Tensile strength, lb./sq. in., as cast	47,900	40,300	45,400
	Tensile strength, lb./sq. in., after eight years' indoor ageing	49,400	34,400	37,200
	Elongation per cent. in 2 in., as cast	5	5	3
	Elongation per cent. in 2 in., after eight years' indoor ageing	2	8	5
	Expansion (growth), in./in. after eight years' indoor ageing	0·0016	0·0001	0·0001
Other properties and constants (as cast)	Brinell hardness	83	74	79
	Compression strength, lb./sq. in.	93,100	60,500	87,300
	Electrical conductivity, mhos./cm. cube at 20° C.	146,000	157,000	153,000
	Melting-point, ° C.	379·5	380·9	380·6
	Melting-point, ° F.	715·1	717·6	717·1
	Solidification point, ° C.	379·3	380·6	380·4
	Solidification point, ° F.	714·7	717·1	716·7
	Modulus of rupture, lb./sq. in.	116,000	95,000	105,000
	Shearing strength, lb./sq. in.	45,800	30,900	38,400
	Solidification shrinkage, in./ft.	0·15	0·14	0·14
	Specific gravity	6·7	6·6	6·7
	Specific heat, cals./gm./° C.	0·10	0·10	0·10
	Thermal conductivity, cals./cm. cube/° C.	0·25	0·27	0·26
	Thermal expansion per ° C.	$27{\cdot}7 \times 10^{-6}$	$27{\cdot}4 \times 10^{-6}$	$27{\cdot}4 \times 10^{-6}$
	Thermal expansion per ° F.	$15{\cdot}4 \times 10^{-6}$	$15{\cdot}2 \times 10^{-6}$	$15{\cdot}2 \times 10^{-6}$
	Transverse deflection, in.	0·22	0·27	0·16
	Weight, lb./cu. in.	0·24	0·24	0·24

* In British Standard Specification 1004(A) and (B) impact figures of 32 and 34 ft./lb. are given.

The compositions of L.33 and D.T.D.424 are given in the following table. Fig. 4 shows a group of vacuum-cleaner parts, pressure diecast in aluminium alloy.

TABLE III

	L.33	D.T.D.424
Magnesium	—	0·15 max.
Silicon	10·0–13·0	3·0–6·0
Copper	—	2·0–4·0
Manganese	0·5 max.	0·7 max.
Nickel	—	0·35 max.
Iron	0·6 max.	0·8 max.
Zinc	0·1 max.	0·2
Titanium	0·2 max.	—
Aluminium	remainder	remainder

TABLE IV

COMPOSITION AND MECHANICAL PROPERTIES OF DIECAST COPPER-BASE ALLOYS

Specifications	*B.S.S. 920*	*B.S.S. 932*	*D.T.D. 174 a.*	*D.T.D. 412*
	Cz.15	*Cz.14*	*C.A.3*	*C.A.4*
Name of Alloy	*Naval Brass*	*Brass*	*Aluminium-bronze*	*Nickel-aluminium-bronze*
Copper	61 min.	59 min.	balance	balance
Aluminium	0·5	0·5	7·5–10·5	8·0–12·0
Zinc	balance	balance	—	—
Nickel	—	—	up to 1·0	3·0–6·0
Tin	0·5–1·5	—	—	—
Manganese	—	—	up to 1·0	up to 3·0
Iron	—	—	1·5–3·5	3·0–6·0
Ultimate tensile strength, tons/sq. in.	22	18	32	40
Elongation per cent. in 2 in.	20	25	20	12

Copper-base Alloys.—Sixty/forty brass has been and is being pressure diecast, but the combined effect of speed of injection into the die and high temperature of the alloy results in brief die life. Consequently brass pressure diecasting is economical only for certain fairly elaborate designs of even section, which could not be produced by, say, hot stamping.

The gravity diecasting process is widely used for the copper-base alloys. Two types of alloy are employed :

(1) Aluminium-bronze, based on 90 per cent. copper, 10 per cent. aluminium.
(2) Alloys based on 60/40 brass.

Aluminium-bronze gravity diecasts with excellent results and with good surface appearance of the finished casting. The strength of the diecast alloy approaches that of mild steel, and since aluminium-bronze preserves good resistance to many forms of corrosion, the alloy in its diecast condition is widely used

TABLE V

SOME QUESTIONS YOUR DIECASTER MAY ASK—AND THE REASONS

No.	Question	Reason
1.	How many of the components will be required during 6–12 months?	Because the cost depends on the quantity to be produced.
2.	What is the maximum output required per month?	Because if this is very large, two or more dies will have to be made.
3.	(*a*) Under what conditions of stress does the component work? (*b*) Will it be used at elevated temperatures? (*c*) Will it be used in any corrosive conditions? (*d*) Will it work in contact with another metal or alloy?	So that a suitable diecast alloy can be recommended.
4.	Can the part be reduced in section, to save weight and cost?	A diecasting is stronger than a sand casting in the same alloy. Thin sections can readily be cast. Often a diecasting is only half the weight of the article it supersedes.
5.	Does any special part of the casting have to withstand exceptional stress?	Because the diecasting can be thickened or ribbed locally to give additional strength where required.
6.	Does the component have to be soldered? (But remember that soldering can often be avoided by making a single diecasting in the place of an assembly.)	Because most diecasting alloys contain sufficient aluminium to make soldering difficult. If it is necessary the diecasting can either: (*a*) Be made in brass. (*b*) Be electroplated before soldering. (*c*) Be made to include a brass insert which can then be soldered.
7.	Where is the part required to be so accurate that machining is necessary?	So that a *small* machining allowance can be included where required.

for components of aircraft, ships, machine guns, food-handling machinery electrical plant, and for many parts of tanks, lorries, and automobiles.

For such purposes as need additional strength, additions of nickel and iron (up to about 5 per cent. of each element) are made. A typical composition is shown in Table IV. Aluminium-bronze is not suitable for pressure diecasting.

When brass is gravity diecast a small addition of aluminium (about 0·2–0·5

per cent.) is made, which has the effect of reducing zinc-oxide formation. Brass gravity diecastings, though not produced quite as extensively as those of aluminium-bronze, offer a tensile strength of about 20–25 tons per square inch, good surface appearance, and an accuracy about the same as that obtained with aluminium-bronze (about plus or minus 0·005 in. per in.). Alloys based on the 60/40 composition, which are gravity diecast, are also shown in Table IV.

Table VI

Designing for Diecasting

(1) Consult the diecaster at the earliest possible stage in your design.
(2) If the article was previously produced as an assembly, ask your diecaster if it can now be made as a one-piece diecasting.
(3) Take the opportunity of a change over to diecasting to improve the design and appearance of the article. An elegant design can be diecast at as low a cost as a crude one.
(4) Any lettering which previously was stamped or otherwise put on the part can be diecast (raised letters preferred).
(5) Holes can be cored accurately in the diecasting. But try to arrange the design so that the number of directions of cored holes is brought to a minimum. A casting with four holes cored in four different directions will cost more than a similar part containing four holes cored in one direction.
(6) Examine the design with the intention of avoiding "undercuts." After the diecasting has solidified, the die must be capable of being opened and cores being extracted. Elaborate undercut designs can, of course, be diecast, but the cost will be higher than a design free from undercuts.

Table VII

Approximate Dimensional Limits for Diecastings in Various Alloys

	Zinc Alloy	*Aluminium Alloy and Magnesium Alloy. Pressure Diecast*	*Copper Alloy. Gravity Diecast*
Minimum wall thickness, large castings	$\frac{1}{16}$ in.	$\frac{5}{64}$ in.	$\frac{1}{8}$ in.
Minimum wall thickness, small castings	$\frac{1}{32}$ in.	$\frac{3}{64}$ in.	$\frac{5}{64}$ in.
Variations from drawing dimensions per in. of length of diameter	± 0·001 in.	± 0·002 in.	± 0·005 in.
Cast threads, external, max. number per in.	24	20	not recommended
Cast threads, internal, max. number per in.	24	none	none
Cored holes, min. dia.	$\frac{1}{32}$ in.	$\frac{3}{32}$ in.	$\frac{3}{16}$ in.
Draft per in. of length or dia. of cores	0·003 in.	0·015 in.	0·020 in.
Draft per in. of length or dia. at side walls	0·005 in.	0·010 in.	0·020 in.

Designing for Diecasting.—To get the best results from diecasting, it is essential for the user and his diecaster to co-operate. It is best to let the diecaster see the designs for a new part at an early stage, and the user should give the fullest possible information that will help the diecaster to recommend the most suitable alloy, production method, and design. The following tables are intended to help the user in his co-operation with the diecaster.

Gravity Diecasting

Casting Design.—Castings designed to suit the use of the metal die mould require individual casting allowances and full details taking advantage of the finer finish produced by gravity diecasting.

Essential requirements of design for the mechanical application of the finished component are exactly maintained, whilst remaining features of casting design are produced to facilitate the easier gravity diecasting conditions whereby continuous contours of metal surfaces are designed by using the fullest limits of the casting allowances. General casting features and allowances of gravity diecastings are as follow:

TABLE VIII

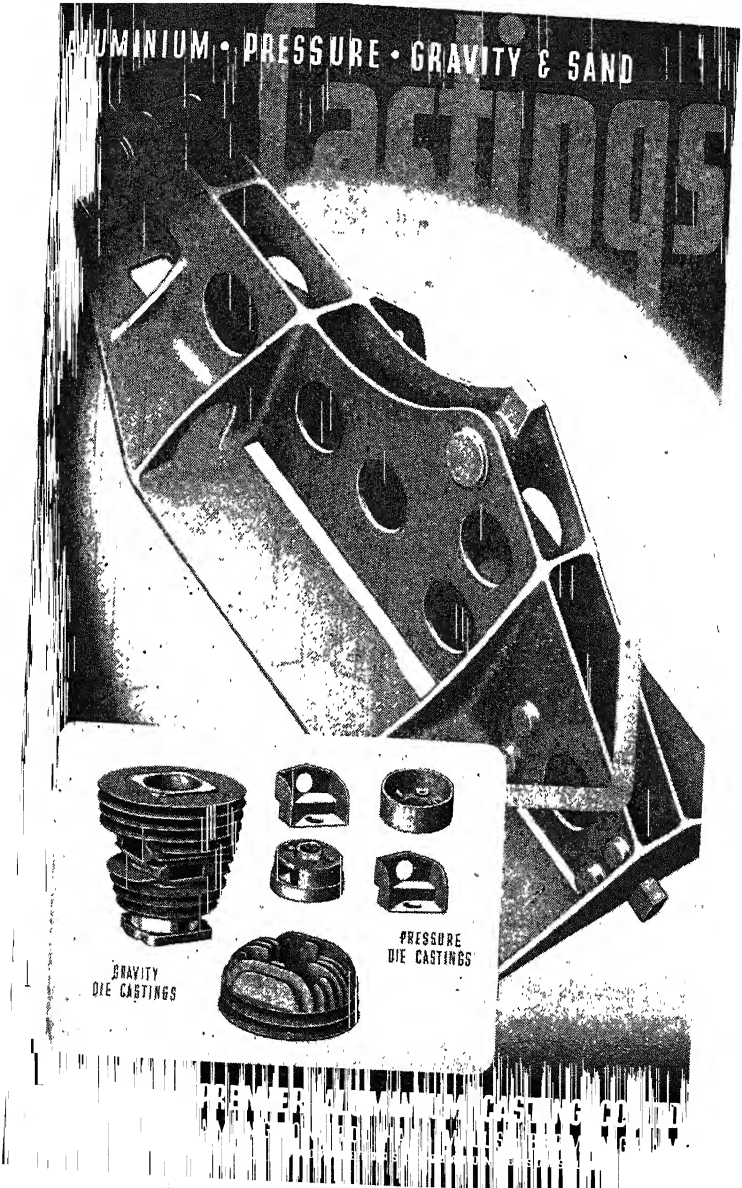
Details	*Data*	*Remarks*
Weight of castings .	1½–40 lb.	Small castings 4 ozs. to 1½ lb. Large castings 8 lb. upwards.
Materials cast . .	Aluminium, magnesium, brass, and zinc	Tin- and lead-base alloys are also cast to a lesser extent.
Casting thickness .	$\frac{5}{32}$ in. minimum	Minimum thicknesses are produced if castings are of even sections—rib form is readily cast.
Contraction . .	1 in 100 nominal	Individual allowances made on irregular form and when castings are required to specified limits.
Draft taper . .	¼–2°	Draft on outside form ¼–2° according to size of casting. Inside form 2° minimum.
Radii and fillets .	⅛-in. rad. minimum	Maximum radii and fillets are required for sound casting results.
Sharp corners . .	Sharp corners are produced by individual arrangement when specified.	
Cored holes . .	⅜-in. diam. minimum	Small holes are not usually cast. Holes over 1½ in. deep cast at ⅝-in. diam. minimum.
Casting limits . .	± 0·02 in.	Maintained when the contraction of individual form is considered.
Machining . .	$\frac{1}{32}$ in. nominal	Allowance for machined finish when specified.

Die-mould Design.—A die mould is designed to enclose a casting with a minimum number of blocks when it is in a natural position for casting.

Each block is of definite design to suit individual casting duties, although it is convenient when possible to introduce companion blocks for easier operation and assembly.

A single or set of blocks for casting work relative to various sections of mould is defined to correspond as follows:

Base: The supporting member upon which the die is operated; it is designed with or without casting form.


ALUMINIUM · PRESSURE · GRAVITY & SAND
castings
GRAVITY DIE CASTINGS
PRESSURE DIE CASTINGS

Form Blocks : Usually a set of blocks operating upon the base ; they cast the greater part of outside casting form.

Runner Blocks : The uppermost blocks of the mould, often made to correspond with the form blocks and fixed to them for more convenient operation.

Cores : The main core parts exist as bottom and top cores located with the base and runner blocks respectively, for casting the inside form of components ; and small cores, known as plugs, side cores, and pins, are introduced to operate through the blocks as required.

Fig. 5 illustrates the application of these die parts, and Fig. 6 indicates the following typical arrangements from which the complete die moulds are developed :

(1) Companion blocks, which are the two halves of a single assembly ; one half may contain the complete mould or the mould may exist wholly or partly within each block.

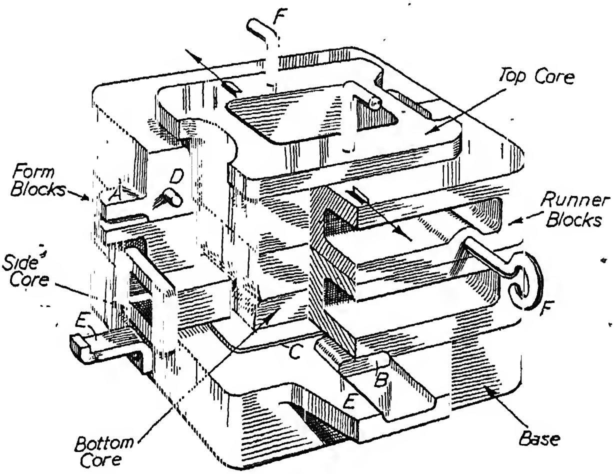


Fig. 5.—Example of gravity die-mould arrangement.

(2) An assembly of blocks operating upon a base with each block designed wholly or partly for casting duties.

(3) Built-up blocks designed to enclose the casting with or without a base.

The complete individual mould designs contain : large and small blocks and various core parts appropriate to the form of the cast component ; the feed of molten metals through runners in its uppermost blocks ; and venting outlets throughout for the dispersal of mould gases.

Running.—Good-quality castings are produced when a maximum feed of molten metal is provided in a single and continuous flow. The molten metal is to flow uniformly from thick to thinner sections at the same temperature throughout the mould. Only one runner outline is used for feeding the mould, and the further outlines undertake alternative work as risers ; the whole set of outlines is generally referred to as the runners.

The runner outlines (Fig. 7) are widely used and are modified to suit individual casting designs ; they provide for :

(1) Running into the top part of the mould upon a mounting or flange face of heavy section. These runners are usually arranged in sets of two or four similar outlines around a top core part, and within the joint of the die blocks or in line with the direction of block withdrawal.

(2) This runner is designed singly for feeding the vertical bulks of metal of outside wall sections and boss faces. It may be arranged in pairs or with the

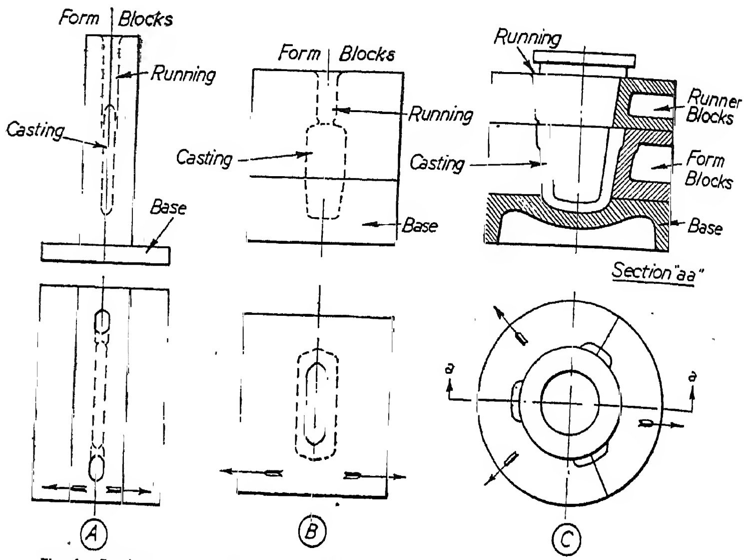


Fig. 6.—Fundamental arrangements of gravity die blocks which are developed for general application.

previous running outline, but can be designed only upon the partings of the die blocks.

A particular feature of design is the gate, which is introduced local to the

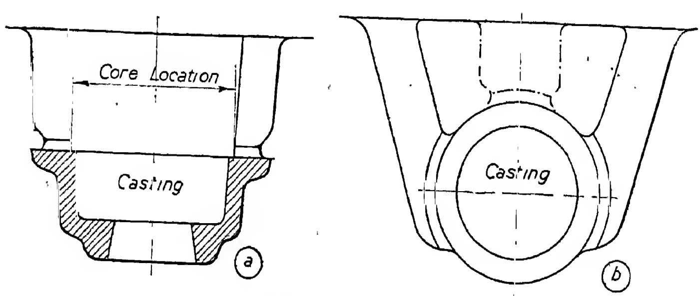


Fig. 7.—Typical gravity die-mould running methods.

mould by reducing the full running section; thus turbulent running is avoided and a single continuous flow is assured.

The weight of the molten metal within the complete set of runner outlines produces a casting of even structure and soundness when the molten metal stabilises

itself within the mould. It is generally accepted that the total weight of runners and risers (runner outlines) is one-third the weight of the casting, i.e.

$$\frac{\text{Estimated weight of casting}}{3} = \text{Total weight of runners.}$$

Supplementary Notes on Runner Design.—When the weight of running cannot be estimated, individual outlines are made of minimum dimensions.

Runner sections are designed completely within one block or in half-sections each side of the parting of die blocks.

Runners must not restrict the opening and closing of the mould assembly.

Core parts are introduced through solid runners for casting duties and also to produce a ring-gate on flange and similar casting faces.

The designed runner of a complete set of runner (riser) outlines is only specified for practical use after sample casting is approved.

Alternative running is available in the use of the other outlines when the

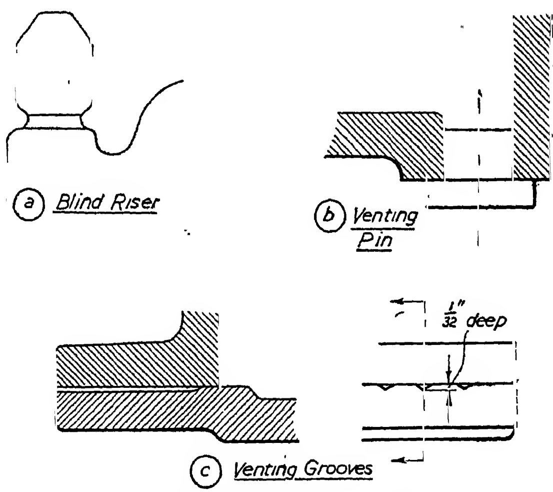


Fig. 8.—Mechanical venting methods.

sections of individual moulds produce misruns contrary to the designed flow of molten metal.

Established running is a definite requirement, and it is strictly maintained.

Venting.—The adequate dispersal of the gases from within the die mould is important, otherwise air and gas occlusions occur in the section of metal and casting is impaired.

Risers provide an exhaust for the natural outlet of gases when they are displaced by a single inflow of molten metal.

The gases isolated in the extremities of mould sections during casting are considered separately. Mechanical venting arrangements are designed similar to the outlines given in Fig. 8.

(1) The blind riser is introduced within the joint of die parts local to the trapped gases. It is made to contain the estimated amount of gases.

(2) Venting pins are designed on prominent form, notably bosses which enclose small quantities of gases. The joint of the pin form provides sufficient outlet for venting purposes.

(3) Small grooves are machined within the die partings $\frac{1}{32}$ in. deep throughout the die mould for general application.

The blind risers and venting pins are introduced relative to the shape of the casting and the nature of running within the design, and then are adjusted to full requirements after sample casting. When sharp corners are required on components, they are produced by arranging a joint in the die mould to coincide in position; venting grooves are also added within the joint to assist reproduction. Radii form minimises the need for venting.

Mould Construction.—The die mould is made of cast iron with steel-core parts; good-quality grey iron is suitable in gravity die working to sufficiently withstand the heat and fusing tendencies of the cast alloys, which are of a lower melting-point. Small complete die and core pins are made from stock steel; large cores are cast in iron; and die blocks are made of cast iron from patterns which are required with a uniform machining allowance on all casting faces of the mould and general allowances elsewhere. Special attention is necessary in maintaining an even thickness of die material: $\frac{1}{2}$-in. general thickness plus $\frac{1}{8}$-in. core facing, etc. (as required), are provided when unspecified.

Die fittings are added. Fig. 5 introduces the general requirements of these features, which are noted as follows:

A, latch and lug fastening;	B, key and slot location;
C, spigot location;	D, dowel location;
E, support brackets;	F, handling details.

The various items are in the position of usual application, especially the different location arrangements. The fastening clamp is typical, and it is cast on as part of the blocks when patterns are ordered.

Full standards of finish and design are necessary on these fittings; firstly to ensure the accurate and rigid assembly of the die blocks, and secondly to withstand the rigours of foundry handling.

Foundry Preparation and Die Operation.—Facilities for the easy operation and the foundry conditioning of the die parts are necessary.

Smoother casting finish and die-mould protection are provided when the casting faces of the die parts are sprayed with a refractory wash. Sodium silicate and whitening solutions give good results when applied to slightly heated blocks.

Movable cores and withdrawn blocks are lubricated dry upon location and bearing faces. Graphite and plumbago are used.

Die moulds are to be maintained at the minimum working temperatures at which the violent chilling of the casting is eliminated. Small die moulds are preheated and the subsequent casting maintains the required temperature; larger die moulds are provided with fixed heating arrangements.

Sample casting confirms the general features of designed work and the sequence of casting operations. Usual die-block movements are arranged as follows:

(1) Removal of top core and other independent die parts.

(2) Withdrawal of main die blocks, leaving the casting within an open mould.

(3) Removal of casting from base recess or fixed mould position.

Sample casting defects are modified immediately, and a closure is made upon further specific design.

The casting arrangement is now available for continuous working, and the mass production of non-ferrous components is established within the gravity-diecasting process.

Pressure Diecasting

Pressure-diecasting methods provide facilities for a complete range of limited applications in which mass production is emphasised, especially in the manufacture of small components.

Economic and mechanical considerations arise when a casting application is proposed:

(1) The cost of maintaining the pressure-casting machine and the die-blocks, and construction expenses.

(2) The physical properties of castings are not of the fullest standards to satisfy every engineering application for which non-ferrous castings are required.

Although these two disadvantages are apparent, they do not noticeably restrict the use of the process, because they are contributory to the definite advantages of applications. The high initial costs of casting development are necessary to provide the facilities of mass production, and castings are obtained inexpensively because maximum production is evident in a minimum of time.

The price per casting therefore decreases when the quantity required is increased, and the cost of the process is justified.

Castings are produced of high-grade outside finish with dimensional accuracy, and are generally to full drawing requirements. The finished casting of domestic non-engineering components, therefore, is very extensive, and limited engineering applications are produced of particular value by the process irrespective of definite physical properties.

TABLE IX

Details	*Data*	*Remarks*
Weight of castings	1 oz.–6 lb.	Complete mass-production process for casting small components.
Materials cast	Aluminium, zinc, lead, and tin	Brass alloys are cast to a lesser extent. Magnesium cast experimentally.
Casting thickness	$\frac{1}{16}$ in. minimum	Minimum thicknesses are produced if castings are of even sections. Small castings readily cast $\frac{1}{16}$ in. thick.
Contraction	1 in 100 nominal	Individual contraction allowed for different alloys.
Draft taper	1°	General requirements.
Radii and fillets	$\frac{1}{16}$ in. minimum	General requirements.
Sharp corners	Detailed casting reproduction very good.	
Cored holes	$\frac{3}{16}$-in. diam. minimum	Diameter sizes of holes are increased when the greater depth is cast.
Casting limits	± 0·004 in.	General casting tolerance.
Machining	$\frac{1}{32}$ in. nominal	Allowance for machined finish when specified.

Casting Design.—Pressure diecastings are of individual design, with sharp outlines of form resulting from the use of the pressure for exactly reproducing detailed work.

Simple contours of component design are maintained without regard to casting thicknesses, because thin and thick sections of casting may occur without disturbing the forced flow of molten metal. Castings of thin section are acceptable.

Raised and recessed details, such as graduated scales, counter discs, knurled form, etc., identify components as pressure diecastings.

Casting allowances are arranged to maintain the design as a completely finished product; general details of design are tabulated above.

Diecasting Machine.—The diecasting machine comprises equipment to produce the inlet of molten metal into mechanically operated die blocks by a single combined operation.

The machine is designed in separate units—(1) the furnace head; (2) sprue cutter; (3) die blocks.

The furnace head contains the injector mechanism and usually the supply of molten metal; a recognised development of design is illustrated in the outlines of Fig. 9. A submerged plunger and cylinder arrangement is fixed in the metal reservoir as a complete unit. An inlet and outlet of molten metal is provided within the cylinder at E and on the extended cylinder channel D respectively. In operation the plunger A is in position at the top of the cylinder, and molten metal flows through the inlet E; the plunger is then moved downwards to close the inlet of metal and then onwards upon the metal to force it under pressure through the outlet and into the die blocks. A direct compressed-air pressure replaces the plunger in alternative designs.

Sprue cutting is introduced to stem the flow of molten metal at the required moment, it is not necessarily a separate mechanism.

Usually the furnace head is arranged to move within its located position, and it is withdrawn from the sprue hole to fracture the partially chilled metal. The sprue is designed so that the extent of the fracture is limited, and the cylinder channel is arranged to allow the uncast metal to flow back ready to be supplemented for the next cast.

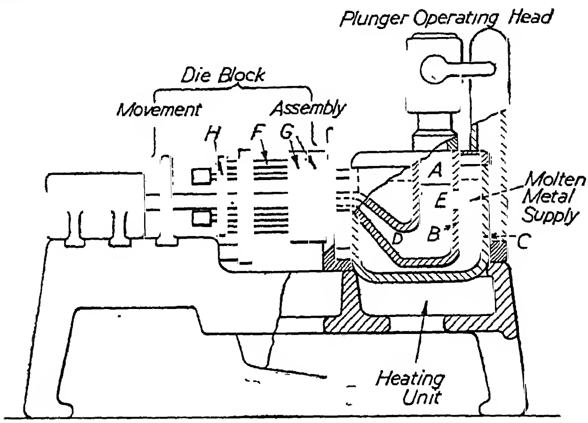


Fig. 9.—General layout of pressure diecasting machine.

The force behind the metal must be cut off immediately sprue-cutting operations are commenced.

Die blocks are arranged to open and close mechanically by utilising the power supply of the machine. This horizontal movement of die operation is required to operate the core F, die blocks G, and ejector pins H independently in a minimum of movements. Withdrawal guide bars and toggle levers of regulated operation are introduced to make die working a single movement. The extent of their arrangement, however, is limited.

Core slides operating within the movable block at right angles to the main die movement increase the possibilities of casting design. They are mechanically operated by pins which are fitted at angles to the fixed blocks. When the blocks are closed the smaller distance between the bottom position of pins maintains the slides in casting position. The greater distance at the top of the pins opens the slides, because there is a location within them which coincides to the angle of the pins.

Complicated die-block workings are evident, although fundamental engineering mechanisms only are designed. Separate manual operations are required when complicated coring is necessary. Finally casting removal is made by the ejector pins within the same movement, and the casting is collected within a cooling space in the lower part of the machine.

Individual machines are developed to make use of hydraulics and compressed air, either separately or combined, so that the metal injecting and casting removal are operated from a single control panel.

Hand-operated machines are not obsolete, and semi-automatic and automatic machines are produced according to the varying extent to which the power supplies are utilised.

Die-block Design.—The die blocks are designed to suit the capacity of individual machines, and this usually provides for fixed and movable halves of two-block construction.

Casting arrangement within two blocks, although restricted, is suitably designed for pressure casting.

The blocks are of separate design for producing small and large castings, as follows:

(1) Small castings are designed in multi-impression moulds, whereby a group of castings is produced from a single inlet of molten metal. Fig. 10 illustrates a typical arrangement of castings within the die blocks; the number of castings is provided within standard-size blocks in convenient positions local to the metal supply. Core parts and ejector pins are introduced through the movable half of the blocks, and are operated separately but in a *single* movement. The full opening of the blocks is not usually required during casting and a minimum of working time is evident, and with the duplication of components per cast it emphasises the fullest application of pressure-diecasting methods.

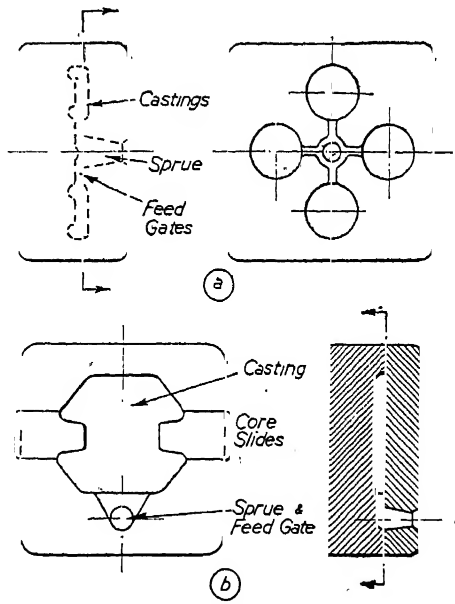


Fig. 10.—General outlines of pressure die-block design.

(2) Large castings are individual developments of pressure diecasting, whereby a single casting is arranged in over-size blocks. The mechanical facilities of assembly are completely utilised and they are supplemented by hand-operated die parts. Ejecting is usually made a separate hand operation to give further mechanical working to the die parts. Die parts must be rigidly fixed when the metal is forced into the mould and whilst it is under pressure. Manual die-part withdrawals take place immediately after casting and the maximum opening of the two main blocks introduces the casting in position for ejecting. The increase in working time for larger casting results is justified when the continuous operation of the machine is fully maintained.

Different mould designs are not usually within the scope of one type of diecasting machine, and several machines are required within the die foundry to provide for the greater number of applications.

Spruee-feed Arrangements.—The molten metal when under pressure does not require the consideration of designed work, although definite positions of supply are necessary within the mould. Sprue holes are therefore arranged in centre and parting-line positions, as given in the Fig. 6, *a* and *b* respectively.

The centre sprue ensures that the molten metal enters the outside sections of a casting or a number of castings at a maximum pressure. It is introduced through the fixed die block and contains a location recess for connection to the injector mechanism.

The parting-line sprue is arranged to provide the molten metal at the most uniform pressure possible throughout the mould; a change in pressure is often noticeable in large castings. The parting-line sprue design is developed from an isolated inlet of molten metal which is introduced through the fixed die block and local to any position where the sprue is required. Sprue holes completely within the parting-line position are evident in individual machine designs when bottom feeds of molten metal are supplied by the injector mechanisms.

The general design of these details is usually maintained and sprue-cutting arrangements are introduced without redesigning.

Venting Arrangements.—Venting requirements are emphasised in pressure diecasting, because the force of molten metal displaces the mould gases in a minimum of time.

The use of pressure restricts the application of venting arrangements, and the design of free outlets for the gases is not possible because the molten metal readily penetrates to the outside of the die blocks.

Venting grooves are used extensively upon the parting lines of the blocks and are relied upon as the only practicable method of reducing the mould gases.

Depth of grooves = 0·005 in. increased to 0·010 in. (outside of die).
Width of grooves—to suit size of casting.

The recognised defect of pressure diecasting is evident in this requirement of design, because it is possible to produce completely non-porous castings only by the total exclusion of mould gases.

Die-block Construction.—Pressure die equipment is made of alloyed steel throughout, to withstand excessive wearing which is evident when machines are at full working capacity.

The die blocks are also water cooled for maintaining continuous casting at a correct working temperature.

Die-block fitting details are added to suit the individual standards of the machine used.

Dimensional accuracy within ± 0·002 in. is necessary upon the completed die block which must be approved before sample castings.

Foundry Preparations and Machine Maintenance.—Diecasting machines are to be foundry serviced before each working: to include lubrication to manufacturer's instructions; furnace-pot replacements as required; the adjustment of individual power supplies; and the alignment of die parts.

Die blocks are given protective refractory treatment, and movable parts within the blocks are lubricated dry with graphite or plumbago.

Sample casting is necessary to establish the die-block operations with a minimum of mechanical movement. The closed assembly of the movable and fixed die parts is designed to ensure exact location with each other or to correspond to the casting outline, and when opened the blocks are adjusted to the limited dimension of casting clearance plus the extent of ejecting.

Machine and die-block movements are therefore simultaneously arranged to complete the final mass-production development of the pressure-diecasting process.

SHRINKAGE OF CASTINGS

The allowance for shrinkage in castings should be (for each foot in length):

	Parts of an Inch
For cast-iron pipes	0·125 = $\frac{1}{8}$
For cast-iron beams and girders	0·1 = $\frac{1}{10}$
For cast-iron cylinders, large	0·094 = $\frac{3}{32}$
For cast-iron cylinders, small	0·06 = $\frac{1}{16}$
In thick breadth	0·156 = $\frac{5}{32}$
In thin breadth	0·156 = $\frac{5}{32}$
Brass	0·17 = $\frac{3}{16}$
Lead	0·31 = $\frac{5}{16}$
Zinc	0·25 = $\frac{1}{4}$
Copper	0·17 = $\frac{3}{16}$
Tin	0·25 = $\frac{1}{4}$
Bismuth	0·156 = $\frac{5}{32}$

PLASTICS

This section deals with each type of plastic compound, outlining the uses to which such materials may be applied, showing the physical and mechanical properties, and describing generally the processes of fabrication.

The data herein are divided into sections dealing with the different types; for instance, thermo-setting and thermo-plastic materials are to be found separately, whilst another deals with cold-moulded compounds.

Thermo-plastic compounds are those which can be deformed by the application of heat, thus assuming any required shape. Such materials remain plastic until cooled, and can be readily moulded into a different shape when heat treated.

Thermo-setting compounds are those which, upon being heat treated or by heat and pressure combined, become changed into an infusible mass. Such materials cannot be deformed by heat treatment, for the resin, being polymerised or "cured," changes its nature to that of a hard substance, which remains unaffected by temperature change.

Acrylic Resins.—This material is comparatively new, being discovered in 1900 by Dr. Rohm, a chemist in Darmstadt. The material was commercially produced in this country about 1930, although some time before in Germany.

The plastic compound produced closely resembles glass, and has, in fact, been often called "organic glass."

The esters are derived or evolved from ethylene chlorohydrin, and the derivative methyl-methacrylate is obtained by converting acetone cyanohydrin. Both esters polymerise under the influence of heat, light, and oxygen.

Acrylic or methacrylic resins cover a range of viscous dopes to moulding powders and sheet materials.

Methyl-methacrylate resin is widely used, due to its possessing the characteristics of glass to which are added excellent optical and mechanical properties, thus providing a most desirable medium for lens making.

Another application of this material is the manufacture of dentures. The fine colours available lend to attractiveness, and apart from this the product is resistant to acids, alkalis, and water, whilst being extremely tough and light in weight.

A common use of methyl-methacrylate sheet is in the construction of aircraft panels, cupolas, and gun turrets, together with several other integral parts of both the commercial airplane and war machine. The sheet is splinter proof, light, most durable, and resistant to easy ignition.

Apart from the available sheet materials, moulding powders are produced for compression and injection moulding. The resin, either water clear or pigmented, is supplied in powder form (or rather granules) for ready application to the mould.

Moulding.—Moulding or forming of sheet materials is a simple process, involving little equipment but restricted to comparatively simple shapes for ease of production. The mould or former is generally made from hard wood or, for small runs, from reinforced plywood. The mould should be smooth and free from any blemishes. A silk covering smeared with petroleum jelly will tend to avoid the transfer of mould defects to the moulding.

In the actual process of manufacture, the sheet, being cut to a predetermined size, is heated and laid over the former. Should stretching be required, it is essential that the sheet be held in a frame and the temperature employed will be considerably above that used for simple contours (250–360° F.). Even the simplest form should be held rigid on the mould until cool; this prevents distortion. The final finishing of the panel, etc., is done by machining, drilling, sawing, trepanning, etc.

Moulding of powder materials by either compression or injection necessitates the use of well-constructed, perfectly finished moulds—made from good-quality steel and capable of withstanding rapid change of temperature.

As this material is thermo-plastic, it will be readily appreciated that some method of chilling is essential to avoid distortion. In compression moulding it is the practice to heat the mould, thus transmitting heat units to the moulding

powder and causing plastic flow. After which the mould is cooled by the passage of cold water around the cavity.

Injection moulding employs the application of a heated material to a comparatively cold mould, but in some cases a water jacket around the mould is necessary to keep the temperature down to below the plasticising level. This applies particularly in respect of long runs and quick production of small parts.

Forms Available

Compression moulding powder.
Injection moulding powder.
Cast rods and sheets.
Solution in organic solvents.
Aqueous emulsions.

British Trade Names and Manufacturers

Perspex—sheets and rods.
Diakon—moulding powders and emulsions.
Kallodent—denture materials.
Transpex I—block material for special optical applications.
All products of Imperial Chemical Industries Ltd., London, S.W.1.

Applications

Aircraft parts, decorative and utility articles, lenses, dentures, adhesives, protective coatings, display material.

Properties

Material: Methyl-methacrylate (cast).
Specific Gravity: 1·18.
Colour Range (sheets and rods): Water clear.
Weight (per in.^{3}): 0·6 oz. (approx.).
Moulding Temperature: 300–360° F.
Water Absorption: 0·3 per cent.
Tensile Strength (lb./sq. in.): 10,000–11,000.
Impact Strength (bar): 0·20–0·25 ft.-lb. (B.S.S. 488).
Breakdown Voltage (volts/mil. at 50 cycles): 500.
Shrinkage (in./in.): 0·001–0·003.
Moulding Pressure: ——
Blister Temperature: 350–370° F.
Modulus of Elasticity: 4–6 (lb./sq. in. × 10^5).
Refractive Index: N_D 1·49.
Dielectric Constant: 3·5 (50 cycles).

Resistance to:	*Effect*
Weak acids	None.
Strong acids	None.
Weak alkalis	None.
Strong alkalis	None.

Organic Solvents:	*Effect*
Alcohols	None.
Oil	None.
Ketones	Soluble.
Esters	Soluble.

Machining Speeds (peripherical)

Drilling	350–650 ft./min.
Milling	5000–6000 ft./min.
Polishing	4000–5000 ft./min.

Cement: Toluol: Glacial acetic acid (warm).

Moulding Processes: Forming by hand. Moulding by compresses.

Cellulose Acetate.—As the name implies, cellulose acetate plastics belong to the family of cellulose derivatives, a popular example being cellulose nitrate or celluloid.

Cellulose is the common base of all the compounds and is produced from cotton linters or sulphated wood pulp.

Cellulose acetate has been known since 1856, originaly being formulated by Schultzenberger and Naudin. These compounds were soluble in aromatic hydrocarbons and were mostly completely acetylated types.

Cellulose acetate compounds are colloids as distinct from pure chemical compounds; they represent solutions in plasticisers. Very briefly, cellulose acetate is made by treating cellulose with acetic anhydride and acetic acid; cellulose acetates and tri-acetate are formed by the reaction. To the resultant colloid several agents are added as plasticisers, amongst the more common being dimethylphalat, triacetin, and di-butyl tartrate. To this is added tri-phenyl phosphate, which retards the rate of burning. The compound with plasticisers is mixed until a jellified mass is produced; to this is added pigments and dyes if required. These are incorporated by a process of rolling until the colouring matter is thoroughly blended with the mass.

For the production of moulding powders the volatile solvents are removed and the material ground into small granules.

Where sheet material is being made, the slabs are taken from the rolls and laminated into solid blocks, which are afterwards sliced into sheets of varying sizes in thickness ranging from about 0·003–1 in. Similar sheets of light gauge are made by casting the dope on to plates.

After seasoning to remove the residual solvent, the sheets are polished by pressing between heated platens which are very highly polished and plated.

Films are manufactured by casting a dope on to a moving polished surface. These films are stripped from the plates and wound on to reels. Such films range in thickness from 0·0003 in.

Cellulose-acetate plastics are easily softened by the application of heat and, being true thermo-plastics, no curing time is required. The degree of plasticity can be controlled only by the amount of plasticiser present in the mix, which is added in manufacture.

The mouldings produced from cellulose acetate are both light and durable. The mechanical and physical properties of this range are outstandingly good, and the process of fabrication is comparatively easy.

Sheet material may be formed into shapes by the same method as employed with other thermo-plastic sheet materials; that is, by heating the sheet to the required plasticity and forming over a wooden mould or former. Alternatively a female mould may be produced, and between this mould and a base plate the sheet is inserted; then by the introduction of compressed air the plastic sheet is deformed until it assumes the shape of the female mould. In either case it is necessary that the material is held rigid.

The moulding of granular material may be carried out by either the compression or injection moulding process. Here again it is essential to ensure that the moulding is cooled before extraction from the mould.

The electrical properties of cellulose acetate are good even after immersion in water, and visual properties are sufficiently high standard to permit the manufacture of vision panels for aircraft. The colour range is unlimited and by the mixture of various colours unique effects can be obtained.

Forms Available

Compression moulding powder.
Injection moulding powder.
Sheet materials and films.
Extruded tubes, rods, and profiles.
Paints, dopes, and lacquers.

British Trade Names and Manufacturers

Bexoid—B.X. Plastics Ltd., Hale End, E.
Cellastine—British Celanese Ltd., London, W.1.
Cellastoid—British Celanese Ltd., London, W.1.
Cellomoid—F. A. Hughes & Co. Ltd., London, N.W.1.
Cellon—F. A. Hughes & Co. Ltd., London, N.W.1.
Erinofort—Erinoid Ltd.; Stroud, Glos.

Novellon—British Celanese Ltd., London, W.1.
Rhodoid—May & Baker Ltd. (Concessionaires), Dagenham.

Applications

Aircraft panels, packaging containers, toys, coverings, electrical components, ornaments, dopes, adhesives, etc.

Properties

Material: Cellulose acetate (sheet).
Specific Gravity: 1·2–1·4.
Colour Range: All colours can be produced; glass clear and opaque.
Weight (per in.^{3}): 0·8 oz. (approx.).
Moulding Temperature: 230–320° F.
Water Absorption (24 hrs.): 1·5–3·0.
Tensile Strength (lb./sq. in.): 6000–11,000.
Impact Strength (ft.-lb. energy, $\frac{1}{2} \times \frac{1}{2}$-in. bar): 0·15–0·6 (C.).
Breakdown Voltage (volts/mil. at 50 cycles): 800–2500.
Blowing (compressed air): 15–20 lb./sq. in.
Shrinkage (in./in.): 0·003–0·009.
Moulding Pressure: 500–2500 lb./sq. in.
Blister Temperature: 250–330° F.
Modulus of Elasticity (lb./sq. in. × 10^5): 20–55.
Refractive Index: N_D 1·50.
Dielectric Constant (50 cycles): 3·5–7·5.
Moulding Temperature: 260–300° F.

Resistance to:	*Effect*
Weak acids	Very slight.
Strong acids	Decomposes
Weak alkalis	Slight.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohols	Soluble.
Oil	Little effect.
Ketones	Soluble.
Esters	Soluble.

Machining Speeds (peripherical)

Drilling	300–600 ft./min.
Milling	4500–5000 ft./min.
Polishing	3000–4000 ft./min.

Cements: Acetone, Dioxan, Benyl alcohol, ethyl lactate, etc. etc.
Moulding Processes: Forming by hand, moulding by compressed air.

Properties

Material: Cellulose acetate (powder).
Specific Gravity: 1·2–1·37.
Colour Range: All colours, including clear and opaque shades.
Weight (per in.^{3}): 0·7–0·8 oz.
Moulding Temperature: Injection 300–400° F.; Compression 250–300°F.
Water Absorption: 1·08–0·28 per cent.
Tensile Strength (lb./sq. in.): 3000–10,000.
Impact Strength ($\frac{1}{2} \times \frac{1}{2}$-in. bar): 0·9–1·6 (C.).
Breakdown Voltage (volts/mil. at 50 cycles): 350–1220.
Shrinkage (in./in.): 0·002–0·006.
Moulding Pressure: Injection, 7000–25,000; Compression, 1500–5000 (lb./sq. in.).
Blister Temperature: ——
Modulus of Elasticity (lb./sq. in. × 10^5): 1·4.
Refractive Index: N_D 1·47–1·50.
Dielectric Constant (50 cycles): 4·5–6·5.

Resistance to:	*Effect*
Weak acids	Little effect.
Strong acids	Decomposes.
Weak alkalis	Slight effect.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohols	Soluble.
Oils	Resistant.
Ketones	Soluble.
Esters	Soluble.

Machining Speeds (peripherical)	
Drilling	350–750 ft./min.
Milling	——
Polishing	4000–6000 ft./min.

Cements: Acetone, cellulose nitrate glues.

Moulding Processes: Compression moulding, injection moulding.

Cellulose Nitrate.—This plastic compound, more commonly known as celluloid, is one of the oldest members of the plastics family. Particularly popularised by the fabrication of toys, combs, and toilet-ware, all of which have been produced in large quantities.

The basic material, nitro-cellulose, was originally prepared by Schoenbein, after which came the development of the plastic material by Parker and Hyatt. During the many years passed since the original inception, development has been made in so far as the control of stability and the reduction of the rate of ignition are concerned. Cellulose nitrate can be defined by its nitrogen content—nitro-cellulose, the explosive, containing approximately 13 per cent. nitrogen, whereas the nitrogen content of the plastic compound is about 11·5 per cent.

In manufacture, cotton linters, carefully purified, are treated with a mixture of nitric and sulphuric acid, and the wet nitro-cellulose produced is available for incorporation into the plastic compound. As a plasticiser, camphor is added and the whole thoroughly mixed with colouring matter. After the major proportion of the free solvents have been extracted by rolling, the whole is subjected to heat and pressure, and by this process is formed into blocks which are ultimately seasoned over a considerable period to remove any remaining solvents and moisture. Finally sheets are cut from the block, and such are polished between steel plates under low heat and hydraulic pressure. Apart from the manufacture of sheet materials in copious quantities, the industry produces a large amount of extruded rods, tubes, and profiles.

Celluloid plastics are extremely tough, very water resistant, and possess good visual properties, although a tendency to discolour when subjected to light for lengthy periods is noted in the glass-clear type. The main snag with this material is the high rate of combustibility, but of recent years this has been considerably reduced by the addition of chlorine and phosphates.

The plastic is resistant to corrosion, and its characteristic toughness makes it eminently suitable for the manufacture of dopes and in the preparation of emulsions and adhesives.

Moulding of cellulose nitrate can be done by compression with a heated punch and die, alternatively by blowing with compressed air. Care must be taken to keep the moulding temperature below the rate of ignition.

Forms Available

Sheet, rod, and profiles.
Extruded tubes.
Emulsions and lacquers.

British Trade Names

Xylonite—British Xylonite Co. Ltd., Hale End, E.

Applications

Toys, fancy goods, in the manufacture of safety glass, covering for tubes, etc.

Properties

Material: Cellulose nitrate (celluloid).
Specific Gravity: 1·3–1·6.
Colour Range: All opaque and transparent colours; also black.
Weight (per in.^{3}): 0·8 oz.
Moulding Temperature: 180–250° F.
Water Absorption: 1·0–3·0 per cent.
Tensile Strength (lb./sq. in.): 5000–10,000.
Impact Strength ($\frac{1}{2} \times \frac{1}{2}$-in. bar): 3·1–5·0 (C.).
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 600–1300.
Shrinkage (in./in.): ——
Moulding Pressure: Compression moulding, 2000–5000 lb./sq. in.
Blister Temperature: ——
Modulus of Elasticity (lb./sq. in. × 10^5): 2–4.
Refractive Index: N_D 1·5.
Dielectric Constant (50 cycles): 6·5–7·4.

Resistance to:	*Effect*
Weak acids	Slight.
Strong acids	Decomposes.
Weak alkalis	Slight.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohols	Soluble.
Oil	Resistant.
Ketones	Soluble.
Esters	Soluble.

Machining Speeds (peripherical)

Drilling	200–400 ft./min.
Milling	——
Polishing	3000–4500 ft./min.

Cements: Acetone-alcohol compounds.
Moulding Processes: Extrusion, moulding by compressed air, compression moulding.

Casein Plastics.—Essentially this material might be described as being produced from milk. In actuality the protein residue left over when the fats have been removed is what can be called the " water " of milk. To this is added rennet powder and thus a junket is formed.

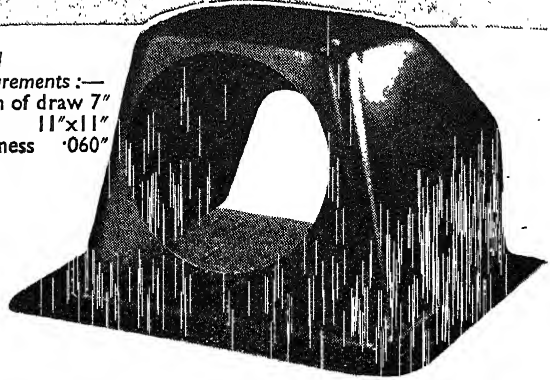
It should be emphasised that by the application of this substance to the production of plastic compounds, humanity is not deprived of an essential foodstuff, for the whey is left when, as in the manufacture of cheese and butter, the food value is extracted.

Casein plastic was developed as far back as 1900 by Spitteler and Krische in Germany, and these men adopted the trade name " Galalith," and under that name casein has become popularly known.

The junket formulated is dried and supplied to the plastic manufacturer in powder form, and to this is added water as a plasticiser, together with the colouring matter. The whole is then kneaded into a dough-like mass and ultimately extruded into rods. Next these rods are pressed together until a sheet is formed, and by this method, with the combination of various coloured rods, a variegated material is produced. To avoid putrefaction it is necessary to immerse the casein plastic in formalin (an aqueous solution of formaldehyde). This formalisation process is carried out over a considerable time—the time of immersion varying from, say, one week to six to eight months. Furthermore, the process of drying, during which the free formaldehyde is dispersed, is carried out over a considerably longer period.

Polishing is effected in the normal way, that is by pressing between heated platens.

Casein, being hygroscopic, is affected by water and atmospheric changes, and in consequence has certain limitations. However, this is a good, cheap plastic



ONE-PIECE SHEET MOULDING
FROM 'CELASTOID'

Illustrating the possibilities for deep-draw effects from 'Celastoid' (cellulose acetate) sheeting. Being thermo-plastic, 'Celastoid' is ideal for small or large production runs. Deep draws and two-way curvatures present little difficulty and true-to-contour pressings are obtainable from inexpensive, quickly made moulds. The cost and time for producing one-off experimental samples are thus reduced to a minimum.

The application of Plastics has wide possibilities. Celanese have always played a leading part in the research and development of this expanding industry, and their technical staff is at the disposal of manufacturers on any Plastics problem.

'Celanese' Plastics

TRADE MARK

The range of Cellulose Acetate Plastics Manufactured by British Celanese Limited includes:

Sheets, foils, rods, tubes and moulding powders.

under the following trade marks,

'NOVELLON', 'CELASTOID', 'WIREWELD'
'CINEMOID', 'CLARIFOIL', 'CELLASTINE'

British Celanese Limited, Celanese House, Hanover Square, London, W.1.

TENAPLAS LTD., 7, PARK LANE, LONDON, W.I

material—with a wide range of colours and capable of being either buff or chemically polished to give a most excellent surface, almost unsurpassed by any other plastic compound. To polish by the chemical method the parts should be immersed in a bath of sodium hypochlorite at approximately 150° F., and after leaving for two to three minutes the parts should be withdrawn and rinsed in clean cold water. It will be found that the hypochlorite bath attacks the surface, softening it, and it is therefore necessary to dry the treated parts in air. The result is a perfectly polished surface. This method is generally adopted for small parts.

Moulding of casein is carried out by extrusion and injection methods, and stock rods and profiles are produced for machining. Button material is also made in blanks, and it will be found that the larger part of buttons used are manufactured from casein plastic.

There have been many developments over the past few years, and apart from stabilising and improving the properties of the material in its general forms, one of the newest applications is that formulated in Italy whereby artificial "wool" has been produced and named "Lanital." This "wool" has been found particularly satisfactory when blended with natural wool.

Scientific research has been carried out, and continues in an endeavour to use the protein residue of other substances, such as soya beans, etc.

Forms Available

Sheets.
Rods, tubes, and profiles.
Discs.
Glue powders.

British Trade Names and Manufacturers

Erinoid—Erinoid Ltd., Stroud, Glos.
Lactoid—British Xylonite Co. Ltd., Hale End, E.
Casein Glues—Casein Industries Ltd., London, S.W.

Applications

Fancy goods, buttons, switch-plugs, fountain-pens, fittings, knife handles, etc.

Properties

Material: Casein plastics.
Specific Gravity: 1·3–1·4.
Colour Range: All translucent, transparent, and opaque colours.
Weight (per in./in.): 0·8 oz. (approx).
Moulding Temperature: 200–230° F.
Water Absorption: 7–9 per cent.
Tensile Strength (lb./sq. in.): 4000–10,000.
Impact Strength ($\frac{1}{2} \times \frac{1}{2}$-in. bar): 1·0 (I.).
Breakdown Voltage (volts/mil. at 50 cycles): 400–700.
Shrinkage (in./in.): ——
Moulding Pressure: 2000–2500 lb./sq. in.
Blister Temperature: ——
Modulus of Elasticity (lb./sq. in. $\times 10^6$): 5–5·7.
Refractive Index: N_D ——
Dielectric Constant (50 cycles): ——

Resistance to:	*Effect*
Weak acids	Decomposes.
Strong acids	Decomposes.
Weak alkalis	Decomposes.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohols	Resistant.
Oil	Resistant.
Ketones	Resistant.
Esters	Resistant.

Machining Speeds (peripherical)

Drilling . . .	300–500 ft./min.
Milling . . .	4000 ft./min.
Polishing . . .	150–300 ft./min.
Turning . . .	300–4500 ft./min.

Sawing by Band or Circular Saw

Circular saw (10 t.p.i.):	5000–6000 ft./min.
Band saw (16–20 t.p.i.):	(Varies)

Shellac.—Shellac is one of the oldest natural plastics known. It is not a chemical entity but an admixture of several compounds. Shellac is formulated in an excrement discharge from the scale-covered body of an ant known as "Laccifer Lacca Kerr." The insect producing the lac is found primarily in India, and the substance excreted is found on growing vegetable matter.

Shellac has the natural properties making for an ideal plastic binder. Perhaps the major application of this resin in the plastics field has been in the manufacture of gramophone records, electrical switchgear and accessories. As a binder for disc records it is quite unsurpassed, for the natural characteristics make for a good hard surface, which is resistant to scratching.

Electrically shellac has a relatively low dielectric constant, and is most applicable to the use of binder for such materials as asbestos and mica, so providing an excellent insulator. The outstanding feature of shellac as an insulator lies in its ability to resist carbonisation. The gases generated when current arcs across the insulator are poor electrical conductors, and in fact tend to resist the arc, turning it away from its course. Chipping and cracking the surface does not impair the insulation property, which proves that the insulation does not depend upon the glazed surface, as is the case with certain other insulating materials.

In manufacture of moulding compounds, the shellac is ground to a fine powder and mixed with various mineral fillers and flock, resin, and pitch.

Shellac may be employed as an industrial laminate. The resin is mixed with a solvent and applied to paper board, after being cured at about 300° F. This has been found to produce excellent coil formers, etc., for the electrical and allied trades.

The colour range of shellac compounds is strictly limited by virtue of the fact that the colour of the natural compound is pale amber or pink, and being that the fillers employed are darker than the resin, it is not possible to produce light or pastel shades. The constituents of the compound determine the final results, but it is possible to get fairly bright reds and blues.

Shellac compositions are true thermo-plastics, but are often combined with thermo-setting resins (urea- and phenol-formaldehyde). The admixture possesses the characteristics of both materials, being easily and rapidly cured and resistant to carbonisation.

Shellac compositions can be moulded by either compression or injection processes.

A considerable quantity of shellac resin is used in the manufacture of varnish and lacquers.

Forms Available

Shellac flakes, slabs, and powder.
Shellac moulding powders or moulded slabs.
Alcoholic varnishes.

British Trade Names and Manufacturers

Crystalate—The Crystalate Mfg. Co. Ltd., Tonbridge, Kent.

Applications

Gramophone records, handles, switchgear and electrical accessories, and varnishes.

Properties

Material: Shellac moulding compositions.
Specific Gravity: 1·1–2·7.
Colour Range: Limited to opaque colours.
Weight (per in.^{3}): 0·75–1·5 oz.
Moulding Temperature: Injection, 180–260° F.; Compression, 240–260° F.
Water Absorption: ——
Tensile Strength (lb./sq. in.): 900–2000.
Impact Strength ($\frac{1}{2} \times \frac{1}{2}$-in. bar): 2·6–2·9 (I.).
Breakdown Voltage (volts/mil. at 50 cycles): 250–600.
Shrinkage (in./in.): 0·002.
Moulding Pressure (lb./sq. in.): Injection, 1000–1500; Compression, 1000–2500.
Blister Temperature: ——
Modulus of Elasticity (lb./sq. in. $\times 10^5$): ——
Refractive Index: N_D ——
Dielectric Constant (50 cycles): 3–4.

Resistance to:	*Effect*
Weak acids	Decomposes.
Strong acids	Decomposes.
Weak alkalis	Decomposes.
Strong alkalis	Decomposes.
Organic Solvents:	*Effect*
Alcohol	Soluble.
Oil	Resistant.
Ketones	Attacked.
Esters	Attacked.

Machining Speeds (peripherical)

Drilling	300–500 ft./min.
Milling	——
Polishing	200–1000 ft./min.

Cement: Methyl-alcohol.
Moulding Processes: Injection moulding, compression moulding.

Styrene and Polystyrene.—Styrene or polystyrene resins are formulated by splitting hydrogen from ethyl benzine. The styrene is polymerised by the action of heat. The chemical construction shows a long hydrocarbon chain.

Styrene was produced in the laboratory as long ago as 1839 and was ultimately developed commercially in 1900 by Krönstein, but the compound as we know it to-day is the result of many developments by different chemists, British, German, French, and American.

Perhaps the most outstanding feature of styrene plastic is the resistance to moisture. Some manufacturers claim their particular product as being entirely resistant to water, others a very low water-absorption factor. Furthermore, these resins offer excellent resistance to acids. The density is very low compared with many substances, and these features, together with the characteristic of crystal clarity, show very favourably.

Whilst styrene plastics are true thermo-plastics, the moulding temperature is higher than many other similar plastics, and consequently much more resistance is offered to deformation by heat. Styrene resins are resistant to alkalis and hydrofluoric acid which, incidentally, attacks glass. As with methyl-methacrylate resins, styrene plastics will carry light through curved sections.

Perhaps the most outstanding feature of this plastic is in its application to the field of radio and electricity. Possessing electrical properties not approached by any other similar moulding compound, styrene resins have provided the electrical engineer with a material long since desired. An extremely low power factor and low dielectric constant, unaffected by acid or alkali and unaffected by normal temperature change, assures constancy in performance regardless of change in conditions. In the manufacture of condensers, polystyrene film of approximately 1 mil. thickness is shown to have a dielectric strength of more than 3,000 volts, thus providing a superb medium for application to ultra-high-frequency radio.

Styrene resins are available as granules for moulding in an extremely wide range of both transparent and opaque colours. This material may be either compression or injection moulded.

Forms Available

Injection moulding powder.
Compression moulding powder.

British Trade Names and Manufacturers, etc.

Distrene—British Resin Products Ltd., Tonbridge, Kent.
Trolitul—F. A. Hughes & Co. Ltd., London, N.W.1.
Transpex 2—Block material for optical applications—Imperial Chemical Industries Ltd., London, S.W.1.

Applications

Electrical and radio accessories, ornaments, display materials, fancy goods, etc.

Properties

Material: Styrene moulding compounds.
Specific Gravity: 1·05.
Colour Range: All transparent and translucent shades.
Weight (per in.^{3}): 0·57 oz. (approx.).
Moulding Temperature: Compression, 220–275° F.; Injection, 300–450° F.
Water Absorption: ——
Tensile Strength (lb./sq. in.): 5500–8500.
Impact Strength: 0·15–0·2 ft.-lb. (B.S.S. 488).
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 600–1000.
Shrinkage (in./in.): Compression, 0·001–0·005; Injection, 0·004–0·010.
Moulding Pressure (lb./sq. in.): Compression, 1000–5000; Injection, 3000–20,000.
Blister Temperature: ——
Modulus of Elasticity (lb./sq. in. $\times 10^5$): 4·6–5·1.
Refractive Index: N_D 1·60.
Dielectric Constant (50 cycles): 2·6.

Resistance to:	*Effect*
Weak acids	None
Strong acids	None
Weak alkalis	None
Strong alkalis	None

Organic Solvents:	*Effect*
Alcohol	None
Oil	None
Ketones	Unstable
Esters	Unstable
	Soluble in aromatic hydrocarbons

Machining Speeds (peripherical)

Drilling	350–600 ft./min.
Milling	5000–6000 ft./min.
Polishing	4000–5000 ft./min.

Cement: Benzine.
Moulding Processes: Injection moulding, compression moulding.

Vinyl Plastics.—This range of plastics includes the polyvinyl-acetal resins and the vinyl esters. The range is comparatively new in the present form, although known in the laboratory for a long time since. Vinyl acetate is polymerised by the application of heat, and by the reaction of heat and hydrolysis a resin is precipitated. The resin is of chief interest in the manufacture of safety glass, the outstanding properties being toughness, resistance to moisture, and stability to heat and light.

Polyvinyl-acetate is used as the base for moulding powders and as an adhesive for foodstuff packaging. Characteristics of note are slow combustibility, lack of odour and taste.

Polyvinyl-chloride possesses similar characteristics plus good resistance to

chemicals. The inherent toughness and resistance to moisture make this material an excellent covering for cables, as tubing for the transportation of liquids, and in the manufacture of washers.

Vinyl-chloride-vinyl-acetate is produced as a moulding powder for injection moulding. Good colour range, resistance to moisture and corrosion provide versatile compounds.

Forms Available

Polyvinyl-acetate
Solution for adhesives.
Moulding powder.

Polyvinyl-chloride
Injection moulding powder, extrusion compositions, pastes and emulsions.
Extruded tubes.

Vinyl-chloride-vinyl-acetate
Injection moulding powder.
Extruded tubes.
Solution for adhesives.

British Trade Names and Manufacturers, etc.

Welvic polyvinyl-chloride extrusion composition.
Welvic pastes and emulsions.
Welvic injection moulding material.
Corvic polyvinyl-chloride.
All products of Imperial Chemical Industries Ltd., London, S.W.1.

Applications

Electrical accessories, coverings, etc.

Properties

Material: Vinyl-chloride-vinyl-acetate.
Specific Gravity: 1·34–1·35.
Colour Range: Transparent, translucent, and opaque colours.
Weight (per in.^{3}): 0·725 oz. (approx.).
Moulding Temperature: Compression, 240–275° F.; Injection, 300–325° F.
Water Absorption: 0·4–0·5 per cent.
Tensile Strength (lb./sq. in.): 8000–12,000.
Impact Strength (Izod) (ft.-lb., $\frac{1}{2} \times \frac{1}{2}$-in. bar): 0·3–0·7.
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 650.
Pressure Resistance (kg.-cm.^{2}): 750–800.
Shrinkage (in./in.): 0·001.
Moulding Pressure: Compression, $\frac{1}{2}$–1 ton/sq. in.; Injection, 1–10 tons/sq. in.
Tearing Resistance (kg./cm.^{2}): 500–600.
Modulus of Elasticity (lb./sq. in $\times 10^5$): 3·5–8·5.
Refractive Index: N_D 1·53.
Dielectric Constant (50 cycles): 0–3·5.

Properties

Material: Polyvinyl-chloride.
"*Welvic*" *Material:* Imperial Chemical Industries Ltd.
Type: P (proprietary).
Specific Gravity: 1·35.
Weight (per in.^{3}): 0·725 oz.
Water Absorption: 0·46 per cent.
Tensile Strength (lb./sq. in.): 3100.
Breakdown Voltage (volts/mil. at 50 cycles): 600.
Permeability to Water Vapour (grammes. cm.^{3}/hr./mm. pressure): $5·5 \times 10^{-8}$.
Elongation at Break at 20° *C.* (per cent.): 270.
Entensibility at 20° *C.* (per cent.): 40.
Recovery of Extension after Removing Load (per cent.): 85.
R.A.B.R.M. Hardness (at 20° C.): Indentation (·01 mm.), 22.

Electrical:
Volume Resistivity at 20° C. (ohms/cm.): 3×10^{13}.
Permittivity at 20° C. (50 cycles): 6·2.
Power Factor at 20° C. (50 cycles): 0·12.
Softening Point: 110° C.
Low-temperature Flexibility: Passes G.D.E.S. 18 Test at −15° C.
Deformation at 70° C.: Passes G.D.E.S. 18 Test.
Extrusion Conditions:

Preheating Temperature on hot rolls	130° C.
Barrel Temperature	140°–145° C.
Head Temperature	140°–150° C.
Die Temperature	150°–160° C.

Resistance to:	*Effect*
Weak acids	None.
Strong acids	Attacked by sulphuric acid and glacial acetic acid.
Weak alkalis	None.
Strong alkalis	Stable.

Organic Solvents	*Effect*
Alcohol	Stable.
Oil	Stable.
Ketone	Unstable.
Esters	Unstable.
Chlorinated hydrocarbons	Fairly stable.
Benzol	Unstable.
Ether	Unstable.

Cement: Metyl-ethyl Ketone.
Moulding Processes: Injection moulding (tubes, etc.), compression moulding.

Fabricating Thermo-plastics.—The first essential to remember in the moulding of thermo-plastic compounds is that such materials being plasticised by heat treatment and deformed, it is necessary to chill the moulding before extraction from the mould. In the manufacture of mouldings by the compression method, it is general to incorporate water cooling in the mould body as well as steam or other heating. In injection moulding the heated plastic mass is forced into a closed mould which is kept at a temperature below the plasticising point. However, should it be that by virture of the high rate of production the heat units built up by transference from the mould are such as to make the mould assume a high temperature, it is then essential that the mould is water jacketed for cooling. These remarks apply generally to all thermo-plastic moulding compounds.

THERMO-SETTING PLASTIC COMPOUNDS

Phenol-formaldehyde Resinoids.—Phenol and phenol-cresol resinoids have been popularised under the name Bakelite.

Both phenol and cresol are derivatives from coal tar and the resins are obtained by the reaction of these compounds with any carbonyl (formaldehyde, benzaldehyde, acetone, etc.).

Phenolic resin is produced by compounding one molecular equivalent of phenol (or phenol-cresol) with one molecular equivalent of formaldehyde, in the presence of a catalyst.

The fundamental reaction was discovered some seventy years ago by Baeyer and developed further by Goldsmith and Story, but it was not until about 1908 that the commercial exploitation of this product was effected by Dr. Leo Hendrik Baekeland (hence the name Bakelite) and by his American contemporaries, Redman and Aylsworth. The name Bakelite is generally applied to this range of resins, but it should be pointed out that that name is the trade mark (protected in America) of the Bakelite Co. Ltd.

In the preparation of the resin the constituents phenol and formaldehyde are boiled, and from this is produced a syrupy fluid soluble in certain alcohols and hydrocarbons, which is unpolymerised resin. If this first-stage material is heated further the result obtained will be a stiff mass which is practically insoluble. By

further treatment this second-stage resin is rendered quite insoluble and infusible. It is these properties that form the key to the whole range of plastics made from these compounds. The first-stage resin is mixed with woodflour, macerated linen, asbestos, flock, or any similar filler, and by the addition of certain accelerators and lubricating agents the admixture formulated gives a resinous compound which can be ground to fine granules, or powder, for moulding, and which, when subjected to the extra heat treatment, will provide the insoluble infusible mass moulded into shape quite indeformable. The actual change of property by polymerisation is due to change in the molecular structure, linking up small molecules or units into larger molecules which, being increased in size, become less mobile and consequently rigid.

The range of colours of the filled moulding product is large and includes a good selection of pastel shades, but due to the nature of the fillers and the natural colour of the resin translucent shades cannot be produced. The general-purpose materials are wood filled, that is, the resin is incorporated with a quantity of finely ground sawdust. The dyestuffs and pigments used are in some cases prone to fading if subjected to strong sunlight or ultra-violet rays. The range of mottles produced is extremely attractive and approaches natural wood finishes. The cast resins produced, which are pure resin without the addition of fillers, are clear glass-like substances. These resins are cast into lead moulds designed to the requirement, or as rods, profiles, etc. These materials are particularly used in the manufacture of imitation jewellery, ornaments, etc.

The moulding powders produced from the processed compound are sold as fine granules for immediate application to the mould. However, it is advisable to tablet the powder into pellets which will serve the dual purpose of ease of handling and also partial exclusion of air. Should granule-form material be used, it is often found that gases generated within the material during the process of flow become trapped and give rise to blemishes in the finished moulding. By compressing the material the majority of the air is excluded by compression. The process of compressing the granulated compound also serves to reduce the loading chamber to the bare minimum. Also where multi-impression moulds are used easy loading is facilitated by the use of pellets. Nevertheless, it is sometimes necessary to use either powder or a combination of powder and pellet.

Phenol-cresol resinoids are cheap and possess excellent mechanical and physical properties—added strength is given by the addition of linen, asbestos, mica, etc.

Laminated sheet materials find wide uses.

The application of this range of products is manifest, the ease of production and low cost being salient points in favour.

Resistance to moisture, acids, alkalis, etc., and low combustibility make such resinoids favourable for most uses.

Moulding may be effected by either compression or semi-injection. In either case water cooling is not necessary, for when properly cured this range of materials is infusible and with adequate ejection from the mould there is no fear of distortion.

There exist many types of compound, each designed for a specific purpose.

Forms Available

Moulding powders.
Varnishes and paints.
Cast resins.

British Manufacturers and Trade Names

Bakelite—Bakelite Ltd., London, S.W.1.
Indurite—Indurite Moulding Powder Co. Ltd., Radcliffe, Lancs.
Nestorite—Jas. Ferguson & Son Ltd., London, S.W.20.
Mouldrite—Imperial Chemical Industries Ltd., London, S.W.1.
Rockite—F. A. Hughes & Co. Ltd., London, N.W.1.
Elo—Birkbys Ltd., Liversedge, Lancs.

Applications

Electrical accessories, general-purpose mouldings, packaging fancy goods, furniture, automobile and aeroplane parts, etc.

Properties

Material: Phenol-formaldehyde moulding compound.
Type: General purpose (wood filled).
Specific Gravity: 1·3–1·4.
Colour Range: Opaque colours and mottles (limited).
Weight (per in.^{3}) (approx.): 0·8 oz.
Moulding Temperature: 280–360° F.
Water Absorption: 0·3–0·4 per cent.
Tensile Strength (lb./sq. in.): 7000–8000.
Impact Strength: 0·16–0·19 ft./lb. (B.S.S. 771).
Breakdown Voltage (volts/mil. at 50 cycles): 200–300.
Shrinkage (in./in.): 0·005–0·007.
Moulding Pressure: 1–1·5 tons/sq. in.
Blister Temperature: 300–370° F.
Modulus of Elasticity (lb./sq. in. × 10^5): 6–7·5.
Dielectric Constant (50 cycles): 7–9.

Resistance to:	*Effect*
Weak acids	None
Strong acids	Decomposes
Weak alkalis	None
Strong alkalis	Decomposes

Organic Solvents:	*Effect*
Alcohol	None
Oil	None
Ketones	None
Esters	None

Machining Speeds (peripherical)

Drilling	1200–2000 ft./min.
Milling	500–1200 ft./min.
Polishing	750–1200 ft./min.

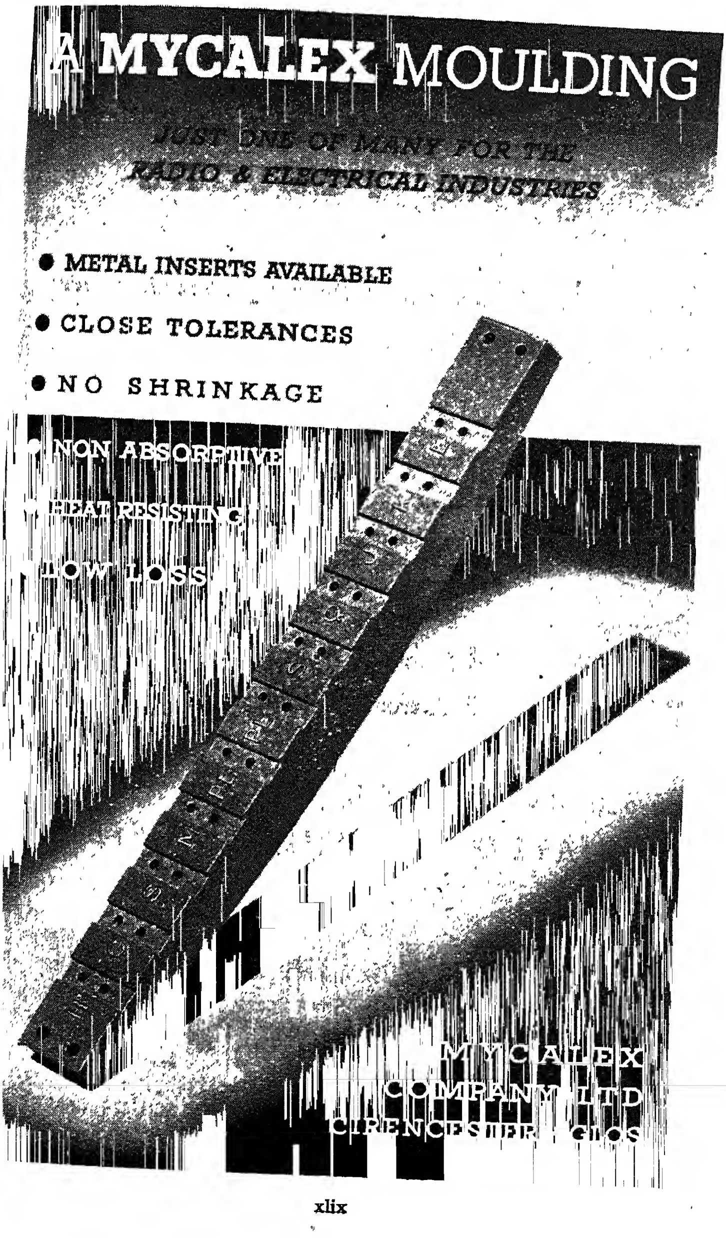
Adhesives: Casein cement: Synthetic resin compounds.
Moulding Process: Compression moulding.

Properties

Material: Phenol-formaldehyde moulding compounds.
Type: Heat resisting (mineral filled).
Specific Gravity: 1·8–2·1.
Colour Range: Black and brown.
Weight (per in.^{3}): 1·07–1·15 oz.
Moulding Temperature: 280–375° F.
Water Absorption: 0·075–0·25 per cent.
Tensile Strength (lb./sq. in.): 4500–6000.
Impact Strength (ft.-lb., ½ × ½-in. bar): 0·10–0·36.
Breakdown Voltage (volts/mil. at 50 cycles): 250–600.
Shrinkage (in./in.): 0·002–0·003.
Moulding Pressure: 1½–2 tons/sq. in.
Blister Temperature: 300–380° F.
Modulus of Elasticity (lb./sq. in. × 10^5): 7–9.
Dielectric Constant (50 cycles): 9–20.

Resistance to:	*Effect*
Weak acids	None
Strong acids	Slight decomposition (oxidisation)
Weak alkalis	None
Strong alkalis	Slight

Organic Solvents:	*Effect*
Alcohol	None
Oil	None
Ketones	None
Esters	None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● NO SHRINKAGE
● NON ABSORPTIVE
● HEAT RESISTING
● LOW LOSS
MYCALEX
COMPANY LTD
CIRENCESTER · GLOS

Machining Speeds (peripherical)

Drilling . . .	300–1200 ft./min.
Polishing . . .	200–500 ft./min.

Adhesives: Casein cements: Synthetic resin compounds.
Moulding Processes: Compression moulding.

Properties

Material: Phenol-formaldehyde moulding compound.
Type: High dielectric (cellulose filled).
Specific Gravity: 1·35.
Colour Range: Black and brown.
Weight (per in.^{3}): 0·78 oz.
Moulding Temperature: 300–350° F.
Water Absorption: 0·3–0·4 per cent.
Tensile Strength (lb./sq. in.): 6000–7500.
Impact Strength: 0·16–0·19 ft.-lb.
Breakdown Voltage (volts/mil. instantaneous): 300–400.
Shrinkage (in./in.): 0·006–0·008.
Moulding Pressure: 1–1½ tons/sq. in.
Blister Temperature: 310–360° F.
Modulus of Elasticity (lb./sq. in. × 10^5): 6–7·5.
Dielectric Constant (50 cycles): 5·8–6·5.

Resistance to:	*Effect*
Weak acids . . .	None
Strong acids . .	Slow decomposition
Weak alkalis . .	None
Strong alkalis . .	Slight

Organic Solvents:	*Effect*
Alcohol . . .	Insoluble
Oil	Insoluble
Ketones . . .	Insoluble
Esters . . .	Insoluble

Machining Speeds (peripherical)

Drilling . . .	800–1200 ft./min.
Polishing . . .	600–1000 ft./min.

Adhesives: Casein cement: Synthetic resin compounds.
Moulding Processes: Compression moulding.

Properties

Material: Phenol-formaldehyde moulding compound.
Type: Water resisting (mineral filled).
Specific Gravity: 1·7–1·9.
Colour Range: Black and various.
Weight (per in.^{3}): 1·05 oz. (approx.).
Moulding Temperature: 280–320° F.
Water Absorption: 0·04–0·07 per cent.
Tensile Strength (lb./sq. in.): 3700–5000.
Impact Strength (ft.-lb., ½ × ½-in. bar): 0·10–0·30.
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 400–650.
Shrinkage (in./in.): 0·002–0·004.
Moulding Pressure: 1–1½ tons.
Blister Temperature: 280–330° F.
Modulus of Elasticity (lb./sq. in. × 10^5): 8–11.
Dielectric Constant (50 cycles): 7–12.

Resistance to:	*Effect*
Weak acids . .	None.
Strong acids. . .	Slight.
Weak alkalis . .	None.
Strong alkalis . .	Very slight.

Organic Solvents:	*Effect*
Alcohol	None.
Oil	None.
Ketones	None.
Esters	None.

Machining Speeds (peripherical)

Drilling	1000–1800 ft./min.
Polishing	700–1000 ft./min.

Adhesives: Casein cement: Synthetic resin compounds.
Moulding Processes: Compression moulding.

Properties

Material: Phenol-formaldehyde moulding compounds.
Type: Acid-alkali resisting (mineral filled).
Specific Gravity: 1·35.
Colour Range: Black.
Weight (per in.^{3}): 0·8 oz. (approx.).
Moulding Temperature: 300–330° F.
Water Absorption: 1·2–2·3 per cent.
Tensile Strength (lb./sq. in.): 3500–5000.
Impact Strength (ft.-lb. energy, $\frac{1}{2} \times \frac{1}{2}$-in. bar): 0·11–0·36.
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 250–400.
Shrinkage (in./in.): 0·006–0·008.
Moulding Pressure: 1·5–2·5 tons/sq. in.
Blister Temperature: 360° F.
Modulus of Elasticity (lb./sq. in. $\times 10^5$): 10–45.
Dielectric Constant (50 cycles): 7–10.

Resistance to:	*Effect*
Weak acids	Excellent resistance with well-cured mouldings.
Strong acids	
Weak alkalis	
Strong alialis	

Organic Solvents:	*Effect*
Alcohol	None.
Oil	None.
Ketones	None.
Esters	None.

Machining Speeds (peripherical)

Drilling	300–1000 ft./min.
Polishing	200–550 ft./min.

Adhesives: Casein cement: Synthetic resin compounds.
Moulding Processes: Compression moulding.

Properties

Material: Phenol-formaldehyde moulding compound.
Type: Shock resisting (fabric filled).
Specific Gravity: 1·3–1·5.
Colour Range: Natural, black, various.
Weight (per in.^{3}): 0·75 oz. (approx.).
Moulding Temperature: 290–320° F.
Water Absorption: 0·6–1 per cent.
Tensile Strength (lb./sq. in.): 6000–7500.
Impact Strength (ft.-lb., $\frac{1}{2} \times \frac{1}{2}$-in. bar): 0·4–2·4.
Breakdown Voltage: 300–450.
Shrinkage (in./in.): 0·003–0·006.
Moulding Pressure: $1\frac{1}{2}$–$2\frac{1}{2}$ tons/sq. in.
Blister Temperature: 290° F.
Modulus of Elasticity (lb./sq. in. $\times 10^5$): 6–7.
Dielectric Constant (50 cycles): 6–11.

Resistance to:	*Effect*
Weak acids	None.
Strong acids	Decomposed by oxidising acids.
Weak alkalis	None.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohol	None.
Oil	None.
Ketones	None.
Esters	None.

Machining Speeds (peripherical)

Drilling	250–800 ft./min.
Polishing	200–500 ft./min.

Adhesives: Casein cement: Synthetic resin compounds.
Moulding Processes: Compression moulding.

Urea-formaldehyde Resinoid.—Urea or carbamide resinoids are thermosetting compounds very similar to the phenol-formaldehyde types in many ways. The basic resin is heat hardening and infusible on curing or polymerisation.

The discovery of urea resin by Ludy in 1883 and later by Goldsmith perhaps heralded the present range of plastics, but it was not until about 1920 that Pollak and Ripper, improving upon the original processes and formulæ, introduced urea plastics commercially.

Urea resins are made by reacting urea (which is a combination of ammonia, hydrogen, carbon monoxide and carbon dioxide) with formalin. Intermediate resins are formed which are ultimately cured to given an infusible resin, insoluble, and resistant to water and organic solvents.

As an improvement on the urea resin British Cyanides Co. Ltd. developed thio-urea; in this compound the oxygen content was supplanted by sulphur.

Present-day materials are a mixture of urea and thio-urea resins. The preliminary or unpolymerised resins are water soluble and crystal clear, and are used in the field of adhesives and coatings for fabrics, straw, etc.

As moulding compounds the resin is mixed with a binding agent plus accelerators, etc., and to this is added the necessary pigments and dyes to produce the required shade or mottle. The main types of resinoid are manufactured—the one wood filled, the other paper filled. In the first case wood flour is used, and a good general-purpose material is produces with unlimited colour range but opaque. The paper- or cellulose-filled variety produces fine tints in translucent materials of unlimited colour range and is, in thin section, almost transparent.

Urea compounds are almost fast to light, although some shades, such as bright reds and blues, have a tendency to darken if subjected to sunlight or ultra-violet rays for a considerable time.

As distinct from the phenol-cresol materials urea resinoids are quite odourless and tasteless. Closures made from this material have no effect upon the contents of the container.

The electrical and mechanical properties of these resinoids are good, and the general character of these materials provides an excellent medium for application to almost every industry.

Forms Available

Compression moulding powders.
Lacquers and finishes.
Laminated sheets, etc.

British Manufacturers and Trade Names

Beetle (translucent)—The Beetle Manufacturing Co. Ltd., Oldbury, Worcs.
Mouldrite—Imperial Chemical Industries Ltd., London, S.W.1.
Scarab—The Beetle Manufacturing Co. Ltd., Oldbury, Worcs.

Applications

Packaging, accessories, ornaments, etc.

Properties

Material: Urea-formaldehyde resinoid.
Type: Wood filled.
Specific Gravity: 1·45–1·55.
Colour Range: Unlimited opaque shades.
Weight (per in.^{3}): 0·85 oz. (approx.).
Moulding Temperature: 300–350° F.
Water Absorption: 1–1·5 per cent.
Tensile Strength (lb./sq. in.): 8000–11,000.
Impact Strength (ft.-lb. energy, ½ × ½-in. bar): 0·15–0·24.
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 200–250.
Shrinkage (in./in.): 0·007–0·009.
Moulding Pressure (tons/sq. in.): 1–2½.
Modulus of Elasticity (lb./sq. in. × 10^5): 11–14.
Dielectric Constant (50 cycles): 7–10.

Resistance to:	*Effect*
Weak acids	None to slight.
Strong acids	Decomposed by oxidising acids.
Weak alkalis	Slight.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohols	None on fast colours.
Oil	
Ketones	
Esters	

Machining Speeds (peripherical)

Drilling	350–900 ft./min.
Polishing	4000–5000 ft./min.

Cements: Resin glues.
Moulding Process: Compression moulding.

Properties

Material: Urea-formaldehyde resinoid.
Type: Cellulose filled.
Specific Gravity: 1·40–1·55.
Colour Range: Unlimited colours, opaque and translucent.
Weight (per in.^{3}): 0·85 oz. (approx.).
Moulding Temperature: 290–340° F.
Water Absorption: 0·5–1 per cent.
Tensile Strength (lb.-sq. in.): 8000–10,000.
Impact Strength: 0·15–0·24 ft./lb.
Breakdown Voltage (volts./mil. at 50 cycles, instantaneous): 200–300.
Shrinkage (in./in.): 0·008–0·009.
Moulding Pressure (tons/sq. in.): ¾–2.
Modulus of Elasticity (lb./sq. in. × 10^5): 12–15.
Dielectric Constant (50 cycles): 8–9.

Resistance to:	*Effect*
Weak acids	None to slight.
Strong acids	Decomposed by oxidising acids.
Weak alkalis	Slight.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohols	None on fast colours.
Oil	
Ketones	
Esters	

Machining Speeds (peripherical)

Drilling . . .	300–600 ft./min.
Polishing . . .	4000–5000 ft./min.

Moulding Process : Compression moulding.

Mycalex.—Mycalex is a combination of glass and mica, and from this combination has been produced a most excellent insulating material, resistant to comparatively high temperatures.

Individually it is found that the mechanical and electrical properties of both constituents are very similar, with consequent limitations as regards machining, etc., but by the combination of powdered mica and finely divided glass, the resultant material after being subjected to heat treatment at about 700° C. was found to be a commercial proposition, inasmuch as the properties of each material were retained but the frangibility of both was eliminated.

Mycalex is entirely inorganic and not subject to carbonisation, resistant to arcing and ignition, and unaffected by acids and alkalis.

As distinct from other ceramic materials, it is possible to mould metal inserts into this material and machining is easily accomplished.

The electrical properties are of particular interest in the application of this material to high-frequency and high-voltage insulation.

The main use of Mycalex lies in its adaptation to the electrical field. The inherent property of being resistant to thermal shock makes possible the process of casting low-fusion-point metals on to Mycalex, thus producing a perfect insulation joint. The simple result of shrinkage gives excellent jointing.

Mycalex was discovered in 1919 and improved until its present form was attained. Strictly speaking, this might be termed a high-fusion-point thermo-plastic.

Forms Available

Rods, blanks, discs, and to special requirements.

British Manufacturer

Mycalex (Parent) Co. Ltd., Ashcroft Road, Cirencester, Glos.

Applications

Insulators, spacing bars, etc., anti-tracking arc-resisters.

Properties

Material : Mycalex.
Specific Gravity : 2·45.
Colour Range : Natural.
Water Absorption (after 48 hours' immersion at 20° C.) : 0·02 per cent.
Oil Absorption (after 48 hours' immersion at 90° C.) : 0·02 per cent.
Tensile Strength (lb./sq. in.) : 6000–7300.
Impact Strength (VDE) : 4–7.
Hardness (Brinell) : 37–47.
Bending Strength (modulus of rupture) (lb./sq. in.) : 9670.
Plastic Yield (Marten's Test) : 450° C.
Resistance to Arcing (VDE Test) : 0–0·3.
Breakdown Voltage (at 20° C., 1 mm.) : 30·5 kV–42 kV.
Surface Resistivity (humidity 60 per cent. ; 17° C.) : 4 × 10^{10} ohms./sq. cm.
Power Factor : The inherent power factor of Mycalex is consistently of the order of 0·005–0·009 at 800 kc. and 0·002–0·003 at 1000 kc., without particular reference to temperature and humidity.

Machining

Sawing

Bandsaw (10–12 t.p.i.): 1400 ft./min.
Slitting Saws (6–8-in. diam., 12 t.p.i.): 120 r.p.m.

Drilling

Up to ¼ in.: 500 r.p.m. } Feed approx. 2 in. per minute for ¼ in., and varying
¼ to ½ in.: 200 r.p.m. } accordingly for larger diameters.

N.B.—Cutting edge of drill (high-speed or carbon steel) should be ground to 120°, whilst the extreme cutting edge should be ground to 60°.

Turning

1-in. diam., 120 r.p.m.; ½-in. diam., 200 r.p.m.
Cutting speed: in either case, 4–6 in./min.

Milling

Side-chip clearance cutters (high speed) are most satisfactory. Spindle speed approximately 100 r.p.m., feed varying according to depth of cut.

Cold-moulded Products.—Various materials have been produced which can be easily moulded cold, and such materials have found ready application to electrical engineering and in the production of handles, etc.

Cold-moulding compounds consist of a filler and binder, the filler being either asbestos, clay, talc powder, mica, etc., or a combination, or alternatively an organic filler such as wood flour. The binders, which very largely determine the characteristic of the finished product, may be divided under three headings—bituminous, synthetic resins and Portland cement.

Bituminous Binder: This consists of a series of solutions compounded from natural resins, such as dammar, copal, ester gum, indene, etc., together with oleaginous substances, castor, tung, linseed, fish oils, etc., together with the addition of stearine or vegetable pitch and asphalts. A selection of these various materials is mixed together and treated similarly to the manufacture of paints and varnishes. The product is then reduced by the addition of thinners (naphtha, coal tar, benzol, etc.) to a given viscosity. To this is added a plasticiser and heat resister.

The binder, comprising some 30 per cent. of the final compound, is added together with oxidising or vulcanising agents and the whole kneaded together, thus ultimately producing a powder possessing the properties required. The compound is then graded and treated to remove the free solvents, and the mixture is ready as a moulding powder. Aluminium stearate is added to assist plastic flow.

The powder is compression moulded, after which the articles thus produced are baked in an oven over a considerable period at gradually increasing temperatures, and by this method the compound is polymerised.

Inorganic Binder: In this type of compound the bitumen is supplanted by a binder of inorganic substances, such as Portland cement, china clay, or silica, all of which are known as the "refractory"-type binders. Mouldings made from the cement types are hardened by immersion in water, and the silica-lime types by treatment in a steam autoclave. To reduce the moisture absorption, creosote, pitch (coal tar), and ceresine are added. Resin-impregnated cold-moulded compounds are baked in an oven after curing in water, and during this process the resin flows, thus rendering the product impervious to water and non-tracking. The resins used are cuomarone-indene resins.

Synthetic Resin Binder: Used in the manufacture of cold-moulded products, produces a material which, being formulated from "A"-stage resin, requires curing.

Such products are generally proprietary and manufactured by those firms marketing the finished product. The chief advantage obtained from these materials lies in the fact that it is cheaper from the point of view of moulds when short runs are required, for by this method one or two cavities will suffice.

The applications of cold-moulding compounds cover the field of electrical accessories and such articles as are necessarily required to be heat resistant (handles, etc.). The synthetic-resin type is mechanically stronger than the bituminous type and the finish is considerably improved. The outstanding properties are the resistance to heat, low cost factor, and the rapid-moulding cycle.

Properties

Material: Cold-moulding compound (organic type).
Specific Gravity: 1·98–2·00.
Colour Range: Limited dark opaque colours.
Weight (per in.^{3}): 1 oz. (approx.).
Water Absorption: 1·5 per cent.
Impact Strength (ft.-lb. energy, ½ × ½-in. bar): 0·4 (I.).
Breakdown Voltage (volts./mil., at 50 cycles, instantaneous): 85.

Shrinkage (in./in.) : 0·000–0·022.
Moulding Pressure (tons/sq. in.) : 2½–4.
Tensile Strength : ——
Dielectric Constant (50 cycles) : 15·0.

Resistance to :	*Effect*
Weak acids	Slight.
Strong acids	Decomposes.
Weak alkalis	Decomposes.
Strong alkalis	Decomposes.

Machining Speeds : Machining properties extremely poor.
Process : Compression moulding.
Not affected by age and will not ignite.

Properties

Material : Cold-moulding compound (inorganic-refractory type).
Specific Gravity : 2·20.
Colour Range : Natural.
Weight (per in.^{3}) : 1·15 oz. (approx.).
Water Absorption : 0·5–10 per cent.
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous) : ——
Shrinkage (in./in.) : ——
Moulding Pressure (tons/sq. in.) : 2½–4.
Impact Strength (ft.-lb. energy, ½ × ½-in. bar) : 0·4 (I.).

Resistance to :	*Effect*
Weak acids	Decomposes
Strong acids	Decomposes.
Weak alkalis	None.
Strong alkalis	None.
Organic Solvents :	No effect.

Machining Speeds : Machining properties extremely poor.
Process : Compression moulding.
Not affected by age and will not ignite.

Laminated Plastics (Thermo-setting type).—Laminated plastics cover a wide range of composite materials used for various purposes. In this range are to be found examples of the application of the thermo-setting compounds as laminates to various "backing" materials.

Materials incorporated in laminated plastics include paper, linen, asbestos cloth, metals, and fine fabrics for decorative work. Two types of laminate are produced, the one whereby a layer, or series of layers, of resin covers the integral base, the other where a surface laminate is applied as finish.

Paper-base Laminates : In the manufacture of this material thin layers of paper are immersed in a solution of thermo-setting resin and thus impregnated. The spool of paper is erected on a mandrel at one end and at the other attached to a revolving spindle which pulls the paper through a bath of the solution. The impregnated paper continues into a condensing oven, and by this method the dry heat partially eliminates the solvent. A certain amount of the solvent is allowed to remain in order that the laminate may be kept pliable. The resin content of the finished product can be adjusted and depends upon the requirement, and may range from 15 to 75 per cent. Either phenolic or urea resin may be employed, but the former is the more popular.

This thin material may now be cut into the required lengths and these lengths placed together to give the required thickness, and pressed in a multi-daylight press to which is fitted a number of polished steel plates to impart the final finish to the sheet. Heat is applied and the resin is polymerised or partially polymerised as required.

Linen-base laminates are manufactured by the same process as the paper-base materials. For the base, good-quality linen or calico may be used, giving added strength. In either case tubes may be fabricated by rolling on a mandrel and curing in an oven by dry heat.

Both of these types of material have found ready application to the electrical and allied industries, in the manufacture of coil formers, insulators, spacing bars, etc. The inherent properties of low power loss and good dielectric strength, even after being subjected to atmospheric changes, commend them to that particular use. Such materials are tough, resilient, and can be handled with great ease. For punching it is essential to heat the sheet in a bath of oil and paraffin, thus retaining the heat without impairing the quality of the finished product. This method of punching is found quite practicable up to about $\frac{3}{16}$ in.

Material made with thicker section is used for the manufacture of gears, separators, spacing discs, etc., and with the introduction of graphite into the bonding agent a material is provided which has proved totally satisfactory in the manufacture of roll-neck bearings. Gears made from such materials are almost noiseless and not prone to attack by acids, alkalis, etc. Furthermore, these products, being non-abrasive, tend to increase the life of a ball race. Adequate lubrication for such bearings can be provided by the application of water as lubricant.

Chintzes, tapestries, etc., have found easy application as laminates for decorative and utility purposes. By covering such materials with a layer of resin the natural beauty of the base material is retained and to it is added a surface which cannot be attacked by atmosphere.

Resin-bonded Board: In this process several sheets of very thin wood are treated with synthetic resin varnishes, and after being pressed together are heat treated. This provides a material which possesses all the characteristics of the natural wood together with the added properties of the resin.

Veneers: Apart from the production of materials incorporating a series of laminations each of which has been impregnated with resin, there is a wide demand for materials which have one layer or laminate on a backing similar to veneers on wood. These may be constructed from plywood faced up with a layer of phenolic or urea resinoid, the resinoid being cemented on with either an alcohol- or water-soluble adhesive. Such materials are used in the manufacture of furniture.

Such veneers may also be attached to asbestos or paper-pulp board, thus making available further additions to the range of products. Another application is that whereby a thin sheet of metal is adopted as the backing sheet for the plastic veneer.

Properties

Material: Laminated sheet (phenol-formaldehyde).
Type: Paper base.
Specific Gravity: 1·3–1·4.
Colour Range: Natural.
Weight (per in.^{3}): 0·7 oz. (approx.).
Moulding Temperature: 275–350° F.
Water Absorption: 0·3–9·0 per cent.
Tensile Strength (lb./sq. in.): 7000–18,000.
Impact Strength (ft.-lb energy, $\frac{1}{2} \times \frac{1}{2}$-in. bar): 0·3–3·0 (I.).
Breakdown Voltage (volts/mil. at 50 cycles): 500–1400.
Shrinkage (in./in.): ——
Moulding Pressure (tons/sq. in.): $\frac{1}{2}$–$1\frac{1}{2}$.
Modulus of Elasticity (lb./sq. in. $\times 10^5$): 5–20.
Dielectric Constant (50 cycles): ——

Resistance to:	*Effect*
Weak acids	None.
Strong acids	Decomposed by oxidising acids.
Weak alkalis	Slight.
Strong alkalis	Decomposes.

Organic Solvents:	*Effect*
Alcohol	None on efficiently cured materials.
Oil	
Ketones	
Esters	

Machining Speeds:
Drilling (up to ¼-in. diam. and ⅜ in. thick): 12,000 r.p.m.
Sawing (peripherical speed) t.p.i., 12–16: 5000–8000 ft./min.
Moulding Processes: Compression moulding. Forming of tubes, etc., on mandrel. Machining and punching.

Properties

Material: Laminated sheet (phenol-formaldehyde).
Type: Fabric filled.
Specific Gravity: 1·3–1·4.
Colour Range: Natural.
Weight (per in.^{3}): 0·7 oz. (approx.).
Moulding Temperature: 280–350° F.
Water Absorption: 0·3–9·0 per cent.
Tensile Strength (lb./sq. in.): 8000–15,000.
Impact Strength (ft.-lb. energy, ½ × ½-in. bar): 0·8–7·5 (I.).
Breakdown Voltage (volts/mil. at 50 cycles, instantaneous): 175–650.
Shrinkage (in./in.): ——
Moulding Pressure (tons/sq. in.): ½–1½.
Modulus of Elasticity (lb./sq. in. × 10^5): 3·5–15.
Dielectric Constant: ——

Resistance to:	*Effect*
Weak acids	None.
Strong acids	Decomposed by oxidising acids.
Weak alkalis	Slight.
Strong alkalis	Decomposes.
Organic Solvents:	*Effect*
Alcohols	None.
Oil	None.
Ketone	None.
Esters	None.

Machining Speeds:
Drilling (up to ¼-in. diam. and ⅛ in. thick): 400–7500 r.p.m.
Sawing (peripherical speed), 12–16 t.p.i.: 3000–5000 ft./min.
Processes: Compression moulding and machining.

Properties

Material: Laminated sheet (phenol-formaldehyde).
Type: Asbestos filled.
Specific Gravity: 1·55–1·80.
Colour Range: Natural.
Weight (per in.^{3}): 0·86 oz. (approx.).
Moulding Temperature: 300–360° F.
Water Absorption: 0·3–2·0 per cent.
Tensile Strength (lb./sq. in.): 7000–17,000.
Impact Strength (ft.-lb. energy, ½ × ½-in. bar): 0·9–5·5 (I.).
Breakdown Voltage (volts/mil., instantaneous): 75–200.
Shrinkage (in./in.): ——
Moulding Pressure (tons/sq. in.): ½–1½.
Modulus of Elasticity (lb./sq. in. × 10^5): 3·5–15.
Dielectric Constant: ——

Resistance to:	*Effect*
Weak acids	None.
Strong acids	Decomposed by oxidising acids.
Weak alkalis	Slight.
Strong alkalis	Decomposes.
Organic Solvents:	*Effect*
Alcohols	None
Oil	None
Ketone	None
Esters	None

Machining Speeds :
Drilling (up to $\frac{1}{4}$-in. diam. and $\frac{1}{8}$ in. thick) : 500–1200 r.p.m.
Sawing (peripherical speed), 12–16 t.p.i. : 1500–3000 ft./min.
Processes : Compression moulding and machining.

Thermo-plastic Laminates.—Laminated plastic sheet is manufactured and finds several uses, but the disadvantage inherent in this material, making for a restricted application, is the fact that such materials are easily deformed by heat and attacked by solvents, acids, and alkalis.

The process of laminating is quite simple and may easily be effected by painting or spraying the faces of each layer with a suitable solvent. Then, by subjecting the constructed laminate to pressure, the air is forced out of the solvent and a welded joint is made. Such process of laminating is of great advantage where it is desired to build up a sheet of material of dimensional thickness in excess of that available. A combination of two materials will give the same effect ; for example, by laminating a thin sheet of water-clear sheet (say 0·030 in.) on to a sheet of tortoiseshell materials (say 0·060 in.) a sheet of thicker material is produced which appears to be a darker shade. This method is often adopted in the manufacture of spectacle frames. It is quite practicable to produce comparatively large quantities in the smallest workshop, for the pressure required is not great and for small pieces an ordinary book press is sufficient. It is essential that the plates of the press be perfectly flat and parallel. By a similar process it is a simple matter to incorporate materials other than plastics in the laminate ; for instance, wire-netting and mesh have been incorporated, thus providing a good medium for use in the production of conveyors, etc., where it is desired to note the movement of the goods being conveyed and yet strength is required. For decorative purposes fabrics, printed to suit, are laminated between two thin sheets of cellulose acetate; alternatively other materials, such as metal foils, paper, etc., may be incorporated. Such laminates are invariably made from cellulose acetate, although similar conditions would prevail were cellulose nitrate used. In either case, after application of the solvent and the final fusing together, it is desirable to leave the treated sheets under pressure for some time (10–60 minutes) and afterwards storing for at least fourteen days in normal room temperature.

The characteristics of the finished products depend upon the properties of the media used, and by combination of different materials it is possible to produce the requirement.

Moulding Presses.—Several types of moulding press have been constructed to suit individual requirements. Motor-driven, pneumatic, toggle, and hydraulic presses are all to be found within the plastics industry, but by far the most popular is the hydraulic press. The essential requirement of this press is the means whereby pressure can be controlled and the compound subjected to pressure to a given value.

The Hydraulic Press : Generally constructed with two or more pillars acting as supports for the movable ram and the static head. The ram may be either up-stroke or down-stroke, but in either case the same principle is served. The action of the fluid under pressure will cause the movable ram to travel under the force exerted upon it. By this means the press may be closed and opened.

The Up-stroke Press : In this the ram is socketed to the underside of the table and moves in an upward direction when under pressure. When the pressure is released the ram falls and thus opens the mould. The ram represents a hollow casting around which is placed a U-shaped leather washer, held in position by a metal ring. This washer prevents the fluid from leaking. Inlet and outlet valves are incorporated in the press or fitted as a single unit, and through these the control of the pressure is made.

The Down-stroke Press : In this the lower part or table is static and the ram moves downward from the head, which is part of the cylinder casting. A separate cylinder mounted above the main cylinder has incorporated an upward-moving ram with pull rods to bring the movable table attached to the ram up into its "open" position.

Prefilling presses have been designed for either up or down stroke, and by this means hydraulic fluid is saved, for the volume required to push back the rams is considerably less than that needed to fill the main cylinder.

Angle presses are a development of the normal hydraulic press but have additional ram or rams, thus giving pressure in a direction at right angles to the main ram. Can be used where it is necessary to employ a split mould.

Injection-moulding Machines.—There are several types of injection-moulding machines, but, irrespective of type, this machine is essentially of very simple principle. Such machines may be either hand operated or mechanical. The hand machine is cheap and easily operated but with a very limited capacity, whereas the power-operated machines can be made to any requirement.

In its original inception the injection machine was a single-cylinder machine very similar in construction to that machine used for the diecasting of metals at high pressures.

Granulated material is fed from the hopper into the injection chamber. Around this chamber is fitted some means of heating, in many cases electric elements often steam jacketed. The injection cylinder is fitted with a plunger or ram, and this ram attached to a toggle which is either hand or power operated. At the commencement of the cycle the dies are closed and at the same time the ram travels forward with the cylinder ; then at the end of the stroke the final pressure is exerted which forces the plastic material into the mould cavity.

The capacity of the machine depends upon the size of the cylinder and ram, and as the compound demands a certain pressure per square inch this necessitates the production of greater power.

Apart from the construction of single-cylinder machines several manufacturers have produced multi-cylinder units.

Extrusion machines work on the same principle as the injection machine with the exception of the mould design. Here the mould is formed to give the required size and profile, and the plastic material is forced through this mould, thus producing a considerable length of moulded section. Also used for the manufacture of rods, tubes, etc.

Hydraulic Installation.—By far the most popular method employed in the manufacture of mouldings is the hydraulic system of supplying pressure to the presses. Water as a liquid is practically incompressible, and being flexible serves as an excellent medium for the transmission of any power imposed upon it. It was Pascal who realised that if he had water contained in a vessel of small sectional area and this was subjected to pressure, this pressure would be magnified in a much larger vessel if the two were placed in communication. In consequence, the hydrostatic or hydraulic press was evolved. A small force-pump with a plunger is connected with the hydraulic cylinder of the press. The lever on the pump serves to increase the purchase. The pump is fitted with inlet and outlet valves and connected direct to the hydraulic cylinder.

For the hydraulic power generated the following will serve as an illustration :

If the pump plunger has an area of 1 sq. in. and that of the ram 50 sq. in., the leverage of the ram is 8 : 1 (that is, the distance from the point where the force is applied to the fulcrum is eight times the distance from the fulcrum to the centre of the plunger), and the distance of plunger from fulcrum is 2 in. By exerting a pressure of 50 lb. at the end of the plunger, we may determine the available pressure between the top and bottom plates of the press.

The factors which increase the force of the machine are :

(1) The force applied at the lever end.
(2) The purchase of the lever.
(3) The sectional area of the ram.

The factors counterbalancing these are :

(1) The sectional area of the plunger.
(2) The distance of plunger from fulcrum.

Therefore, if we divide the product of the former by that of the latter we may obtain the total pressure exerted on the ram.

Thus : $\dfrac{50 \times 8 \times 50}{1 \times 2} = \dfrac{20{,}000}{2} = 10{,}000$ at 75 per cent. efficiency (i.e. 25 per cent.) of the theoretical work is lost in friction)—a total pressure of 7500 lb.

The force exerted by any liquid on any surface with which it is in contact is always perpendicular to that surface. If we have a vessel of any shape, the pressure exerted by the liquid against the surface of the sides and bottom of the

vessel will act at right angles to the surface under consideration for as long as the liquid remains at rest. From this it can be seen that the total pressure on the horizontal base of the vessel would be found by multiplying the area of the vessel by the depth of the fluid. In a vertical pipe containing a liquid, the pressure at the base depends upon the area of the base and the height at which the liquid stands. This pressure is technically termed a "head," and the term "20 ft. head of water" conveys that we have a column of water 20 ft. high. It will be appreciated that a column of water 20 ft. high will exert twice as much pressure as a column 10 ft. high. From this it will be seen that were a head of water available at such an elevation to supply several thousand pounds of pressure, much useful energy would be available on tap, but, on account of the height to which the container would need to be placed, such a system is impracticable, and to facilitate the "storage" of the hydraulic pressure it is necessary to install an accumulator.

The Accumulator: The action of the accumulator is quite simple, and can be readily understood from the following: Water is forced by a pump through the hole in the centre of the ram into the hydraulic cylinder, causing this to lift and raising the chamber with it. The cylinder is supported on a ram, and around the hydraulic cylinder proper is enclosed a chamber containing ballast, the weight of which will determine the capacity of the accumulator. The water is charged into the cylinder through the entry hole in the ram. In the ballast chamber around the cylinder is placed any heavy material, iron, sand, etc., to produce the load desired. If we have a ram 4 in. in diameter and should we require a working pressure of 2500 lb. per sq. in., what amount of ballast must we place in the chamber?

Thus: area of 4 in. = 12·5 sq. in. multiplied by 2500 lb. gives us 3125 lb., and deducting from this figure the weight of the ballast chamber and cylinder we can find the net weight of the material required to act as ballast.

In some hydraulic accumulators it will be found that the ram remains static and the cylinder slides over it; in other instances the ram carrying the load is forced out of the hydraulic cylinder, but in either case the same effect is obtained.

As the pump feeds high-pressure hydraulic water into the ram of the accumulator the accumulator rises, and as this hydraulic water is drawn off the accumulator cylinder with ballast falls. To prevent the pump from supplying the high-pressure liquid when the accumulator is not being tapped, a spring-loaded valve is incorporated in the pipe line immediately following the pump; alternatively a deflecting valve is operated by means of a rod carrying an adjustable tappet, which is lifted when the permissible stroke is made.

The capacity of the pump installed depends upon the maximum requirements to operate the battery of presses during the peak period. A large-capacity accumulator permits the use of several presses.

Some presses are fitted with independent pumps, thus eliminating the necessity for an accumulator, but where a battery of presses is to be used the accumulator is considerably less expensive.

Pipe lines for hydraulic fluid should be constructed from solid-drawn heavy-walled mild-steel tube, with a smooth bore. For pressures up to 3000 lb. per sq. in. the wall thickness should be sufficient to take 1¼ Whitworth gas thread and a bore of approximately 1 in. For branch lines these sizes are reduced proportionately. Joints should be made with robust screwed sockets and fitted with soft sealing washers.

Moulds.—Several types of moulds are constructed, depending upon the design of the article to be produced, the process of manufacture, and the quantity required. The manufacture of large quantities will call for multi-impression moulds, that is, moulds whereby many impressions may be produced with each lift, thus eliminating the necessity for several single units.

Compression Moulding: These moulds may be classified under their respective headings of hand moulds, semi-portable moulds, and fixed automatic moulds.

Hand Moulds: In some instances where it is necessary to fit intricate inserts, it is possible to use only a mould which can be removed from the press and assembled after extraction of the moulding. This will consist of two plates carrying respectively the punch and die, or alternatively two female impressions. Such moulds cannot be expected to give optimum production ,and it is therefore

usual to duplicate them, thereby using one mould for moulding whilst the other is being stripped and recharged for continued operation.

Semi-portable moulds represent those moulds wherein one half of the mould remains fixed to the press head, but where it is necessary to remove the other half for extraction of the moulding and loading of the cavity.

Fixed Automatic Moulds: Such moulds remain permanent fixtures in the press; both the top and bottom plates are screwed to the platens and are not removable after each moulding cycle. Invariably this type of mould is fitted with automatic ejection.

As an instance, we will take the moulding of small knobs, having incorporated in them a metal boss. In the integral design of the mould a pin is incorporated on to which the metal bush is fixed with a common push fit. The pin continues through the mould, and is extended until the under side rests upon a bar. This bar is in turn attached to a rod which is secured to the press head and made movable. When the press is opened to a predetermined distance the rod is moved upward, thereby pulling the cross bars attached in one or the other direction (depending upon the type of mould), and by this means the pins seated on this cross bar (or bars) are moved, thus ejecting the mouldings. Such moulds lend themselves to ease of production and great speed, for it is necessary only to load the inserts and moulding material, the rest being quite automatic.

A further sub-classification is necessary.

Flash Moulds (Fig. *a*): Simple type of mould for use where the moulding form is of simple design and where several impressions are incorporated in one mould. The separate impressions are generally machined from standard material and made so as to fit into standard bolsters.

Positive Moulds (Fig. *b*): This type of mould is that whereby the whole of the pressure is applied to the moulding compound until the formation is completed, there is no "flash" area. Used for certain forms or designs where the cubic capacity of the moulding above its centre line is equivalent to more than that below.

Positive Flash Moulds: These are designed with a flash or land area around the moulding, and give positive pressure on the moulding after the excess material has been ejected. Such moulds are employed where it is desired to avoid the possibility of porosity around the finishing edge. The punch is extended beneath the land level. Such extension is very small and need not exceed 5–10 thousandth inch. Furthermore, the clearance between the diameter of the punch and that of the die is very slight, thus producing a thin flash which may be easily removed by tumbling.

Sub-cavity moulds are those wherein the flash area is continuous and connected between each individual impression. The pressure is evenly distributed over the whole of the mould area. The moulding material is equally dispersed and ease of ejection is facilitated.

Split Moulds: Such are necessary when the design calls for pressure in two directions (as supplied by an angle press); alternatively when ejection is not by the straight-draw principle (as with a coil former, etc.). Here the mould is partially loaded and the insert piece fitted, whilst the other part of the mould is fixed to the platen.

Injection Moulds: Used for injection and extrusion processes. The mould represents two plates which are engraved or otherwise machined to carry the contour of the moulding required plus the insertion of pins, etc. Both plates are connected by two or more dowels, which assure alignment and facilitate locking by the inclusion of an eccentric ring for hand machines or by some other method for power-operated machines. The material is fed into the closed cavity through a feed port and each impression is connected by a channel.

General moulds for moulding both thermo-plastic and thermo-setting materials should be machined from good-quality steel, either mild steel surface hardened (where hobbing is required) or from nickel-chrome or other alloy steels. The finish on the mould will determine the finish on the moulding produced.

In either instance the moulds should be located by dowel pins assuring alignment.

The width of the land or flash area will serve to build up the moulding by limiting the rate of flow, for this will act as a construction. This can be more

readily appreciated in conjunction with the powder materials, especially the thermo-setting variety, for these materials have a definite curing time and will harden up during flow.

Heating of Moulds.—Apart from the supply of pressure to the moulding material, the most important feature is the application of the heat units with which to plasticise the mass. No plastic material is a good conductor of heat, yet it is essential that adequate heat be applied. With the thermo-setting materials the chemical change during reaction causes heat units inside the mass, thus assisting the supply of heat to the core of the mass. Gas, steam, and electricity are all used as the source for heat supply to moulds. Furthermore, platens are constructed to which the mould is attached and which are cored out to permit the flow of water or oil for heat conductivity.

Modern gas-heating engineering has developed to the extent of producing efficient installations which are economical in both capital and running costs. The products of combustion have been dispersed so as to avoid fouling the atmosphere. This system is particularly useful where the installation is comparatively small. Gas heating is applied to platens or moulds by bar burners of various types. Thermostatic control can be incorporated with ease, and the cost of upkeep is very low, for replacement parts are essentially cheap.

Steam heating is perhaps the most popular method employed in the plastic industry, especially where a large battery of presses is to be served. Steam supply requires boiler plant of such capacity to suit the requirements of the shop. The amount of steam required to heat the material is low, and the majority of the steam supplied goes to the heating of the mould and platen. Small presses of, say, approximately 9 in. × 9 in. platen area can be rated at about 15 lb. of steam per hour. Should chilling of the moulding be necessary, as with thermo-plastic materials, this would be appreciably higher, probably ten times as much.

The boiler is normally run at about 180 lb. per sq. in. and the steam passed through a reducing valve to give about 150 lb. pressure. A boiler approximately 8 ft. in diameter by 25 ft. long will give about 5000–6000 lb. of steam per hour at 160 lb. pressure.

Steam-heated platens are used to transmit the heat to the mould proper; these should be very robust in construction to withstand considerable crushing load. Such platens are usually constructed by boring through a plate of mild steel. Several ports are incorporated, connected at each end to give continuous radiation. The rate of heat transference depends upon the diameter of the ports. The loss of heat depends upon the proximity of the ports to each other. Should these be far apart, the loss of heat will be greater than the heat applied. Therefore the midway point will be at a lower temperature than the ends.

Steam-heated moulds are similarly constructed.

Steam connections should be made from flexible metal hose. This is constructed from a seamless copper pipe. The bend of the flexible—the flexible is made in a "U" shape—should conform to a certain diameter for a definite length. The longer the stroke of the press the greater the diameter will be. Steam traps should be incorporated to release the water of condensation.

Electric heating may be applied to either platen or mould or both, and is usually effected by means of an immersion-type heater element or alternatively (as in the case of platens) with the metal-clad bar or strip type. Electrical heating is both clean and under certain circumstances very economical (if on tap at a cheap rate). Such mode of heating is quite easily controlled thermostatically by inserting in the circuit the bi-metallic-strip type thermostat. When the temperature of the surrounding area rises to the predetermined level, the contacts are broken until such time as the heat is dissipated and the temperature drops below the set level, the bi-metallic strip then assumes its normal position and the contacts are made, thus permitting electrical current to flow.

It is necessary to insulate the moulds to prevent loss of heat by radiation, thus conserving heat energy. The calorific value of, say, one pennyworth of electrical heat energy will be found to be somewhat less than a similar amount of steam-heat energy. Furthermore, it is necessary to incorporate a somewhat larger element than is necessary for normal running, to provide a sort of boost for initial heating; this applies at the beginning of the day when the moulds are cold. In view of this, it would not be a practicable proposition to employ this

mode of heating in the production of thermo-plastic compounds, for the necessity for water cooling after each moulding cycle would make the cost of heating by electricity prohibitive.

Principles of Moulding.—This will be briefly outlined under the three distinct headings—compression moulding, injection moulding, and semi-injection or transfer moulding.

Compression Moulding: By this process the material to be moulded or formed into shape is so formed by the action of pressure upon the substance. The simple mould consists of a punch and die, and into the die cavity is charged the moulding material in either pellet or powder form. Power is converted into mechanical energy and this is exerted upon the moulding compound, thus compressing it and forming the required shape. However, both thermo-setting and thermo-plastic compounds require heat by which the flow of the material is achieved, and for this purpose a means of heating the mould is incorporated.

Moulding of heat-treated plastics may be defined as that method whereby an already heated substance is subjected to pressure whilst in the mould, and thus changed from its original powder form into a viscous mass which finally hardens on cooling or curing.

Injection Moulding: This is the method whereby the granular compound is charged to a heated container which causes it to flow. Having attained the correct viscosity, the plastic mass is forced into a closed mould by a plunger through a nozzle. The mould is opened for ejection only when it is required to eject the moulding.

This may be defined as being the method whereby the plastic mass is injected into the closed mould.

Semi-injection Moulding: Used primarily in the manufacture of mouldings from thermo-setting compounds when such compounds do lend themselves to the normal compression method.

In this instance, the mould is designed with a loading chamber placed above the actual mould cavity. The moulding compound in granule form is supplied to the loading chamber, which is heated, and then by means of a punch is forced through ports into the mould cavity. By this means it is possible to mould-in fine inserts in the shape of pins, etc., which would otherwise become distorted by the plastic flow. It is also found that the mechanical properties of the finished moulding are greatly improved, for in actual fact the material is thoroughly cured throughout. Tubes with thin wall section may be produced by this method.

This is, in fact, a combination of compression and injection moulding, for in the first place the compound is subject to pressure and ultimately forced into the mould cavity.

The Mechanism of Moulding

The following will give an outline of the mechanism of the moulding cycle.

Thermo-plastic Materials

Pressure available as required.
Heat available at required temperature.
Water cooling available.

(1) Load moulds with inserts (if any).
(2) Load material to mould.
(3) Close mould.
(4) Open mould.
(5) Eject moulding.

N.B.—When the mould is closed the heat units are transferred to the moulding compound and the material flows; when the mould is entirely closed, the heat is turned off and the cooling medium turned on and left on until the moulding is ejected.

Thermo-setting Materials

Pressure and heat available to requirements.

(1) Load moulds with inserts.
(2) Load pellets or powder (or both).
(3) Close mould.

N.B.—During this time the material is flowing and curing. When the mould is entirely closed it may be rightly assumed that the flow is completed.

(4) Curing time (this will be determined by the size and sectional dimension of the moulding, and can be anything from a few seconds to several minutes).

(5) Open mould.

(6) Eject mouldings (if not ejected automatically), and blow out with compressed-air gun any small particles of moulding powder which may have remained.

(7) Lubricate mould. (This may be necessary where the walls are approaching parallel.)

Chemicals Used in Conjunction with Moulding

The following compounds may be used as solvents, plasticisers, or cements where indicated. This list is not complete.

Alcohols
- Methyl alcohol.
- Ethyl alcohol.

Acetic Acid
- Glacial acetic acid.

Acetates
- Methyl acetate.
- Ethyl acetate.
- Butyl acetate.
- Amyl acetate.

Ketones
- Acetone.
- Methyl acetone.
- Diacetone alcohol.
- Mesityl oxide.

Glycols
- Ethylene glycol.
- Mono ethyl ether of ethylene glycol.
- Mono butyl ether of ethylene glycol.
- Di ethylene glycol.
- Di ethylene dioxide.
- Glycol mono acetate.

Chlorinated Compounds
- Methylene chloride.
- Ethylene dichloride.
- Dichlor ethyl ether.
- Carbon tetrachloride.
- Trichlorethylene.

Esters
- Ethyl lactate.
- Butyl lactate.
- Amyl lactate.

CAST RESINS

Cast resins are essentially different from moulding compounds in that no filler is incorporated in the product. Liquid phenolic resins are formulated by the combination of phenol and formaldehyde in the presence of one of several catalysts. To this is added certain other materials, such as plasticisers and others, to impart flexibility and strength. Various pigments are incorporated to give the desired colours. The liquid resin is poured from the vacuum still into moulds, which are usually made of lead. To produce these moulds a steel dipping arbor is made, and this is immersed in a bath of molten lead. After cooling in water, the lead mould is removed from the arbor by attaching the whole to a vibrator. The liquid resin being poured into the mould sets upon cooling. Rods, tubes, and profiles are so produced over a range of sizes.

Rods: $\frac{1}{4}$-in. diameter upwards. Tubes: $\frac{1}{2}$-in. diameter; wall thickness approximately $\frac{1}{8}$ in. and upwards. There is no restriction to size providing

special moulds are available. Blocks also are cast and afterward sliced into sheets. Special castings may be made in any form, typical examples being knife handles, ornaments, etc. The resins may be either glass clear, opaque, or translucent.

Cast resin of this type is a good insulator and of particular interest in its adaptation to the electrical trades. The range of phenolic resins is extensive, and many types with different properties can be produced, some thermo-plastic, some thermo-setting. Thermo-plastic casting resins have found application in the manufacture of plastic dies, formers, jigs, and tools.

Forms Available

Sheets, rods, profiles, button material, casting resins, lacquers, and adhesives.

British Trade Names and Manufacturers

Catalin: Cast-resin products; thermo-setting materials.
Catafil: Casting resins; thermo-setting.
Cataplas: Casting resins; thermo-plastic.
Catalin Limited, Waltham Abbey, Essex.
Bakelite: Thermo-setting casting resins.
Bakelite: Resins and insulating varnishes.
Bakelite Limited, London, S.W.1.
Rockite: Thermo-setting casting resins.
Rockite: Lacquers, adhesives, and insulating varnishes.
F. A. Hughes & Co. Ltd., London, N.W.1.

Properties

Material: Cast resin (thermo-setting).
Colour Range: Various.
Type: No filler.
Specific Gravity: 1·3–1·8.
Weight per in.^{3}*:* 0·8–0·9 oz.
Moulding Temperature: 180° F. (bending temperature).
Water Absorption: 0·1–0·2 per cent.
Tensile Strength (lb./sq. in.): 3000–5000.
Impact Strength (½ × ½-in. bar): 0·16–0·20 (Izod).
Breakdown Voltage (volts/mil. at 50 cycles): 250–350.
Shrinkage (in./in.): 0·009–0·011.
Blister Temperature: 300–370° F.
Modulus of Elasticity (lb./sq. in. × 10^5): 7–10.
Dielectric Constant: 8–10.

Resistance to:	*Effect:*
Weak acids	None.
Strong acids	Some decompose.
Weak alkalis	Slight.
Strong alkalis	Decompose.

Organic Solvents:	*Effect:*
Alcohol	None.
Oil	None.
Ketones	None.
Esters	None.

Machining:

Turning: 200 ft./min.
Sawing (band saw; ¼ in. × 14 t.p.i.): 1500 ft./min.
Grinding: 14-in. diameter, 1800 r.p.m.
Pumicing: 12-in.-diameter mop, 1800 r.p.m.
Polishing: 12-in.-diameter mop, 6000–7000 r.p.m.

Cements:

Casein glues, synthetic resin glues.

NYLON

Nylon is the generic name given to synthetic fibre-forming polyamides. From these materials various forms of monofilaments and yarns, possessing the characteristics of strength, elasticity, resistance to water and acids, etc., can be made. Nylon monofilaments are used extensively to replace natural bristles and fibres. Nylon made in the form of gut is used as fishing lines and in surgical use.

Nylons are in appearance similar to silk, hair, and gut, but are essentially synthetic. Due to the large range of raw materials, many different forms of nylon can be made. Nylon is made up of long-chain molecules and can be extruded into filaments. To form a monofilament, the nylon is melted and forced through apertures into water, where it solidifies. A further step in the process orientates the molecules, pulling them together and thus increasing the strength of the filament.

The important characteristics of Nylon are low melting-point and low density. The melting-point of nylon is approximately 10–15 degrees lower in the presence of oxygen. The water absorption is dependent upon the relative humidity of the surroundings. Nylon elongates on wetting. The rate of ignition is very slow. Nylon is characterised by extreme toughness and resistance to abrasion.

Forms Available

Injection moulding powder.
Monofilaments (sutures, synthetic gut, artificial bristles).

British Manufacturers

Imperial Chemical Industries Ltd., London, S.W.1.

Properties

Material: Nylon.
Specific Gravity: 1·14.
Colour Range: Various.
Weight (per in.^{3}): 0·8 oz. (approx.).
Moulding Temperature: 280–320° C.
Water Absorption:
50 per cent. relative humidity—2·6 per cent.
100 per cent. relative humidity—7·6 per cent.
Elongation in Water: 3·7 per cent.
Tensile Strength:
0 per cent. relative humidity—58,500 lb./sq. in.
50 per cent. relative humidity—53,600 lb./sq. in.
100 per cent. relative humidity—43,000 lb./sq. in.
Modulus of Elasticity:
0 per cent. relative humidity—7 lb./sq. in. × 10^5.
50 per cent. relative humidity—4·5 lb./sq. in. × 10^5.
100 per cent. relative humidity—1·7 lb./sq. in. × 10^5.
Refractive Index: N_D 1·53.
Dielectric Constant (1000 cycles):
0 per cent. relative humidity—4·5.
50 per cent. relative humidity—6·3.
Power Factor (1000 cycles):
0 per cent. relative humidity—0·027.
50 per cent. relative humidity—0·117.
Softening Temperature: 264° C. (in inert atmosphere).

Resistance to:	*Effect:*
Weak acids	None.
Strong acids	Some dissolve.
Weak alkalis	None.
Strong alkalis	Some decompose.

Organic Solvents:	*Effect:*
Alcohols	None.
Oil	None.
Ketones	Soluble.
Esters	Soluble.

Also soluble in phenol, meta-cresol, xylenol, formic acid, oxidising acids, concentrated hydrochloric and sulphuric acids.

POLYTHENE

Polythene is the general term for a range of solid polymers of ethylene, first discovered and prepared in I.C.I. research laboratories by subjecting ethylene to extremely high pressures under carefully controlled conditions. These products are sold under the registered trade name "Alkathene."

Alkathene is a saturated straight-chain hydrocarbon in which the individual molecules are of the order of 1000 carbon atoms long. This chemical structure gives good water resistance and electrical properties.

Extract from I.C.I. Bulletin No. 5.

Applications

Electrical moulding, cable coverings, etc.

Forms Available

Compression moulding powders.
Injection and extrusion moulding compositions.
Rods, films, and chips.

Properties

Material: Polythene moulding compounds.
Specific Gravity: 0·92.
Colour Range: White, grey, pink translucent colours.
Weight (per in.^{3}): 0·5 oz. (approx.).
Moulding Temperatures:
Compression, 125–130° C.
Injection and Extrusion, 130–160° C.
Water Absorption: Nil.
Tensile Strength (lb./sq. in.): 1300–1700.
Impact Strength: 40–200 ft.-lb. (0·5-sq. in. section; 150-lb. Avery machine).
Breakdown Voltage: 1000 volts/mil.
Dielectric Constant (50 cycles–10^8 cycles): 2·3 at 20° C. falling to 2·15 at 100° C.
Power Factor: 0·0003.

Resistance to:	*Effect:*
Weak acids	None.
Strong acids	Some attack at increased temperature (100° C.).
Weak alkalis	None.
Strong alkalis	None.

Organic Solvents:
At elevated temperatures soluble in the following:
Benzene, xylene, toluol, tetralin.
Petroleum products (turpentine, paraffin, oils, etc.).
Trichlorethylene, carbon tetrachloride, chlorobenzene.
And similar hydrocarbons and chlorinated hydrocarbons.
Insoluble in ketones and esters, but affected by ethyl alcohol.

PYTRAM

Although not falling into the general category of plastics, pytram is a cellulose fibre material bonded with special-type adhesives on the laminated principle.

Developed in 1937 from a material of an allied character, then used for the production of commercial displays, its potentialities were so impressive that a thorough investigation was carried out into its possible uses in industry, particularly in the aircraft industry. The results of such investigation proved that the scope of its utility was almost unlimited, and it was adopted almost immediately on the outbreak of war for the production of lightly stressed fairings for Service machines. From its inception it proved to be an ideal medium for the production of complex mouldings, and especially suitable where lightness and ease of production were an essential factor.

The processes of its manufacture are not too costly, particularly where double curvatures predominate, the moulding process involved with this material giving

complete freedom from all the difficulties and expense normally associated with curvatures in several planes.

The natural inherent resilience of pytram greatly resists indentation, and the very nature of the material alone suggests that, in fatigue under vibration, it has qualities far superior to other materials generally used. Its moisture resistance is adequate for most purposes, and quite obviously there can be no corrosion. In weight it is almost a quarter that of duralumin.

The two outstanding achievements of this material have been the production of the first paper jettison tank and complex gun-heating and camera-heating ducts; in the latter the material normally withstands temperatures from minus 70° C. to plus 130° C., and, with additional treatment, up to plus 200° C.

Moulding.—A great advantage of the moulding process is that it does not require expensive tools. A master former is prepared in wood from which a plaster mould is made. A number of casts are then taken from this mould, on which the component is built up in laminations. Owing to the malleability of the cellulose-fibre base when in its wet state, it readily conforms to the contours of the former. When the predetermined laminations are completed, the covered cast goes through a drying period in specially heated drying rooms with a controlled temperature. After drying, the surface of the component is processed to ensure a smooth finish prior to being removed from the cast and fabric-covered. The edges are then tape-bound to prevent the ingress of moisture. The whole is finally treated to withstand all weathering conditions.

When required for electrical screening, pytram can be metal-sprayed without difficulty by any of the recognised processes.

Forms Available

Owing to the specialised technique of manufacture, pytram is available only in the final moulded form.

British Trade Name and Manufacturers

Pytram—Pytram Ltd., Pytram Works, New Malden, Surrey.

Applications

Aircraft components, air-conditioning and heating ducts.
Complex mouldings, decorative and display material.
Mouldings for research and prototype development.

Properties

Material : Pytram (3 grades).
Specific Gravity : 0·73–1·04.
Colour Range : Any colour finish required.
Weight (per in.^{3}) : 0·4–0·6 oz. (approx.).
Moulding Temperature : Cold.
Water Absorption (24 hours' total immersion) : Nil–0·4 per cent.
Tensile Strength (lb./sq. in.) : 3000–8000.
Impact Strength ($\frac{1}{2} \times \frac{1}{2}$-in. bar) : 2·3–3·6.
Breakdown Voltage (volts/mil. at 50 cycles) : 21 volts.
Shrinkage (in./in.) : ——
Moulding Pressure : Formed by hand.
Blister Temperature : ——
Modulus of Elasticity (lb./sq. in. $\times 10^5$) : 2·7–10·0.
Refractive Index No. : ——
Dielectric Constant : ——

Resistance to :	*Effect :*
Weak acids	Slight.
Strong acids	Destroyed.
Weak alkalis	Slight.
Strong alkalis	Slight.
Organic Solvents :	*Effect :*
Alcohols	None.
Oil	None.
Ketones	None.
Esters	None.

Processing:
Cutting, drilling, and riveting may be carried out with no more difficulty than that experienced with wood. Large holes are recommended to be punched.
Moulding Process: Forming by hand.

Low-temperature Melting Alloys.—Whilst not strictly a member of the plastics group, this range of materials possesses characteristics very much in keeping with some resinous plastics plus important inherent properties.

The materials described herein are known as cerro alloys, and find many applications in engineering and the manufacture of cold mouldings. Such metals have a low melting-point and require very simple equipment. They contain a large amount of bismuth, providing the low melting-point plus the characteristic property of expansion on cooling.

The materials here described are the developments of the combined efforts of the Cerro de Pasco Copper Corporation of the U.S.A. and their associate company in England, Mining and Chemical Products.

The matrix metal is used to attach dies and punches to the holding plates. It is not a solder, but, by undercutting the base of the tool or the shank of the spindle and inserting those parts into a machined plate and pouring in the molten metal, this will harden and expand, thus giving rigid keying. Upon hardening, it is found that expansion will provide a job mechanically sound.

The parts thus treated should be firstly pre-heated to prevent solidification of the metal before the space has become completely filled.

British Trade Names and Manufacturers
Cerromatrix—Mining & Chemical Products, Manfield House, 376, Strand, London, W.C.2.

Applications
Securing blanking dies to plate, lamination dies, compound dies, forming dies, holding machined parts, etc.

Properties

Specific Gravity: 9·5.
Weight (per in.^{3}): 0·343 lb.
Melting Temperature: 248° F.
Pouring Temperature: 300–400° F.
Tensile Strength (lb./sq. in.): 13,000.
Brinell Hardness: 19.
Elongation: Less than 1 per cent.
Compression Strength: 16,000 lb./sq. in. in 30 secs., 8,000 lb./sq. in. in 5 mins.
Expansion: 0·002 in./in.

Another type of fusible metal is that made from lead and bismuth. This may be used for the production of master patterns in foundry work. The fluid metal can be cast on plaster, wood, or paper moulds.

British Trade Name and Manufacturers
Cerrobase—Mining & Chemical Products Ltd., London, W.C.2.

Properties

Specific Gravity: 10·3.
Weight (per in.^{3}): 0·38 lb. (approx.).
Melting Temperature: 255° F.
Pouring Temperature: 270–310° F.
Tensile Strength (lb./sq. in.): 6,100.
Brinell Hardness: 10·2.
Elongation: 64 per cent.

Applications
Apart from the use as a pattern metal, this may be used for proof casting for forging dies, autoclave heat transfer medium, fusible metal for safety purposes, etc.

A further type of easily fusible metal is that known as Woods Metal. This is

a combination of tin, cadmium, lead, and bismuth. It has a very low melting-point. This finds ready application in use as a filler in the bending of tubes, profiles, etc. The tube to be bent is filled with the alloy, and can then be bent to any required shape without fear of fracture. Extruded profiles can be similarly treated.

British Trade Name and Manufacturers

Cerrobend—Mining & Chemical Products, London, W.C.2.

Properties

Specific Gravity: 9·4.
Weight (per in.^{3}): 0·38 lb. (approx.).
Melting Temperature: 160° F.
Pouring Temperature: 200–250° F.
Tensile Strength (lb./sq. in.): 5990.
Brinell Hardness: 9·2.
Elongation: 140 per cent.

NOMENCLATURE

Amino Plastic.—Synthetic resin made from amino or amide compounds—example: urea-formaldehyde compounds.

Amorphous Mass.—A mass devoid of any crystalline structure.

Bulk Factor.—The ratio by volume of loose powder or granules, to the resultant moulded product.

Cold Flow.—Distortion caused by the application of a force greater than the elastic limit.

Condensation.—The fusion of two or more molecules by chemical reaction, with the separation of water or some other substance.

Curing.—Change of a resin, as binding agent, from a soluble-fusible condition, to the insoluble-infusible state, by chemical action.

Dielectric Strength.—The voltage gradient at which continuous electrical discharge will take place between two electrodes when the material serving as dielectric is placed between the two plates and a potential difference is applied to the two plates.

Extrusion Moulding.—The formation of a definite shape or form by forcing a heated substance through an orifice made to the form of the cross section of the shape required.

Injection Moulding.—The formation of a definite shape or form by forcing a heated substance into a mould cavity being kept at a lower temperature than the moulding compound.

Laminating.—The unity of several sheets of material into a solid block by the application of a resinous binder.

Modulus of Elasticity.—The stress required to produce a unit distortion.

Phenolics.—Phenol-formaldehyde resins.

Thermo-plastics.—Materials which may be deformed under pressure and heat.

Thermo-setting Plastics.—Materials which when formed under pressure and heat remain infusible and cannot be deformed.

Plasticity.—The inherent capacity for assuming and retaining the shape of the mould.

Polymerisation.—A chemical change whereby a new product is formed, the molecular weight of such being a multiple of the original substance. The products of such reaction are given the name polymer.

Co-polymerisation.—When two or more substances polymerise at the same time giving a complex product with properties from either polymer alone.

Power Factor.—The ratio of power loss in watts to the product of voltage and current.

Resinoids.—Term generally applied to thermo-setting resins as distinct from natural resins.

Transfer Moulding.—A term generally applied to the semi-injection moulding of thermo-setting plastics.

The reader is referred to *Newnes Plastic Manual* for information on manufacturing methods.

COOLANTS AND CUTTING COMPOUNDS

A coolant reduces the degree of heat generated by the friction of cutting at the tool nose or point. (Some materials are of course machined dry.) Its temperature being lower than that of the tool or the work at the point of cutting, it chills or cools both, and the heat, passing into the cooling stream, is partly carried away with it into the sump or other receptacle in which the coolant is collected. The coolant or cutting compound serves as a lubricant, not, perhaps, at the point of cutting, but elsewhere, i.e. it makes the passage of the chips easier and smoother, which ultimately means that less heat is generated at or near the cutting edge, and both tool and work are, in consequence, cooler.

WATER SOLUTIONS

Water	*Water+Alkali*+Soap*
Used for	*Used for*
Grinding	Chucking Grinding Drilling Drawing Forming Stamping
	On
	18/8 stainless steel, soft steel (1), wrought iron, zinc (2)
	Use
	(1) 4 parts water, 1 part naphthenic base soap. (2) 3–5 per cent. aqueous soap chip solution. A little lard oil may be added. *Caustic soda, Sodium carbonate, Sodium silicate, Sodium resinate.

The second reason for using a cutting compound is that it makes possible the employment of higher cutting speeds.

The third reason is to give a better finish to the work. Less power is required when a coolant is used, and tool wear is reduced.

Classes of Coolant.—Coolants are divisible into three main types—those consisting mostly of an oil; those comprising water or water solutions; and those of emulsified type comprising blends of oil and water. The cutting oils may themselves be subdivided into organic, mineral, and blended. Included among the organic oils are all those derived from vegetable plants, animals, fish, or other organic substances. Mineral oils are principally petroleum products, and cost less than organic oils. Blended oils, as their name suggests, are compounded of organic and mineral oils.

Organic Oils.—Of the organic cutting oils lard oil and fish oil are probably the most important types; other oils used for the same purpose are cotton-seed oil, rape-seed oil, and the like. It is not often that mineral oils are exclusively used as coolants in metal cutting, though paraffin is extensively used for certain

work, as is turpentine; they are generally compounded either with emulsions or with organic oils.

Water Solutions.—Water solutions are not often used for lathe cutting. They are mainly of use in grinding. Their great disadvantage is a tendency to cause corrosion, so that soda is often used to prevent this, but borax, sodium carbonate, or sodium silicate can also be employed.

Emulsified Coolants.—Emulsified coolants are broadly divisible into three main types. The first is an emulsion of water, a thick soap solution, and a mineral oil. The second is a mineral oil blended with soft soap or some other alcoholic soap solution. The third is a sulphurised or sulphonated oil neutralised and blended with a soluble oil.

Choice is governed by a number of considerations, which include type of work to be lubricated and type of metal being cut.

Chart of Coolants.—A comprehensive chart on page 357 shows the type of coolant best suited to a particular operation or material.

Metals Best Cut Dry.—Austenitic manganese steel is one of these. It is essential to the drilling and working of this material that no coolant or lubricant

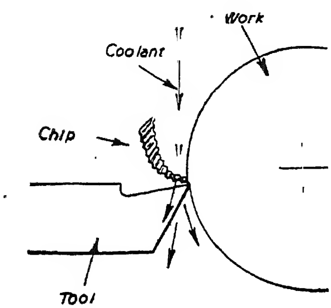


Fig. 1.—The correct direction of the stream of coolant.

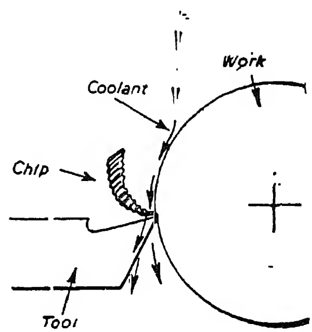
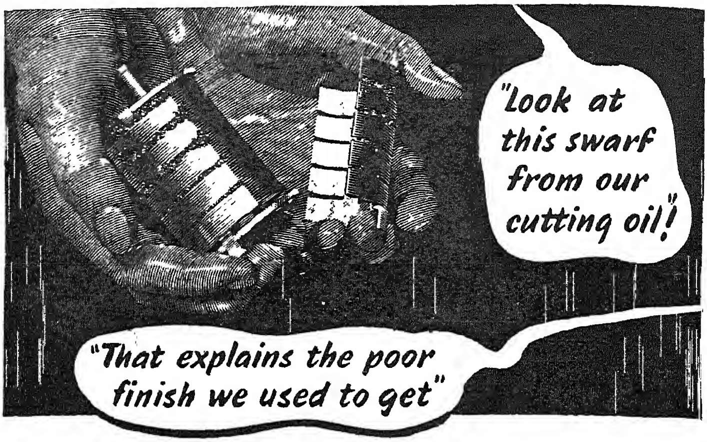


Fig. 2.—The incorrect method of using coolant.

should be used. Austenitic manganese steel work-hardens with extreme rapidity on the surface. The essential factor in its successful machining and working is the generation of sufficient heat at the point of contact to soften the skin and prevent work-hardening, so that the tool can get under the surface before any work-hardening has had time to take place. Once a coolant is employed, the heat becomes insufficient to achieve the desired result, the steel work-hardens, and the tool will not make an impression. The same thing obtains if the tool is allowed to stop in the cut. Work-hardening sets in and makes the resumption of cutting almost impossible. Hence, manganese steel must always be machined and drilled perfectly dry. Many small turning jobs with light cuts are also done dry. Steel castings are often rough planed without a coolant, though here a coolant would not necessarily be a drawback. Some slotting is, on occasion, done dry. Cast brass is also machined dry, but in this respect care should be exercised, as by no means all brass castings are of the correct type for dry machining, and some would be better machined with the aid of a coolant. Cast iron, when being machined with tools tipped with tungsten carbide, is often dry machined.

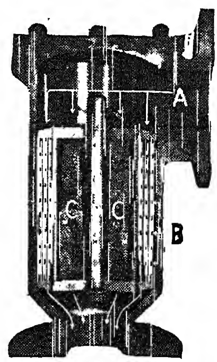
Direction of Coolant Stream.—The direction of the stream of coolant is important, and some attention should be paid to this point. There is a right way and a wrong way, in this as in other operations. In Fig. 1 the right way is indicated, as compared with Fig. 2, which shows the wrong way. In Fig. 1 the coolant is being directed straight to the point of maximum heat generation, and is not wasting its cooling power on a less acutely heated bulk of metal. It is better,



MAGNETIC FILTRATION SOLVES THE PROBLEM OF FERROUS SWARF

Philips Magnetic Filter extracts ferrous contamination from lubricating oils and coolants. It will trap particles even as small as one micron, which would pass through the usual filtering systems.

A really clean lubricating oil and coolant means less machine wear, and an unblemished mirror finish on precision work—points which are of vital importance today. Send now for full particulars of the complete range of Philips Magnetic Filters.



HALF-SECTION OF FILTER.

A *Oil or coolant flows between sections of cages.*

B *Ferrous swarf is trapped in air-gaps between sections of cages.*

C *Powerful permanent magnets.*

PHILIPS

PHILIPS INDUSTRIAL

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on the whole, to have a less forceful stream with a greater area of contact, i.e. a slower but thicker stream, rather than one thin and fast; this is for the reason that the greater volume distributes cooling power and removes heat more extensively, and the smaller velocity introduces less splash.

Removal of Chips.—The cutting compound also removes chips, drillings, etc. If these are allowed to accumulate at the tool nose, they retain heat and prevent it from becoming dissipated, with the result that all the disadvantages of excessive heat generation are enhanced. The coolant removes a good proportion of these chips, thus lessening heat, a fact of particular importance when deep holes are being drilled or recesses machined out.

Coolant Reclamation.—Economy can be effected by systematic reclamation of oil from the sump, the chips being strained out by various methods and afterwards gravity drained. Where the amount of machining carried out is considerable and the quantity of chips large, ordinary gravity draining is replaced by mechanical centrifuging of the chips, which means that a much higher percentage of the oil is reclaimed from them.

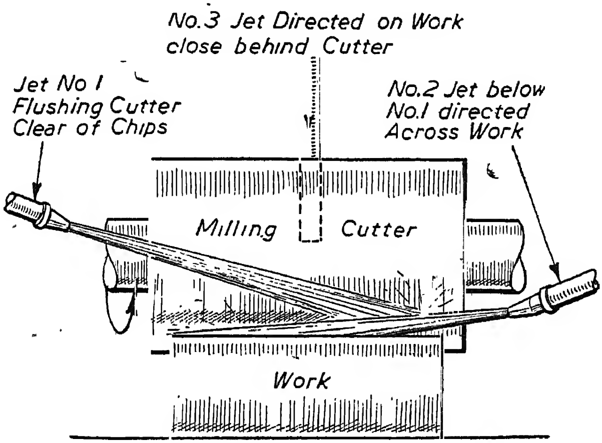

Fig. 3.—A milling operation.

Centrifugal Separation.—The centrifugal method comprises inserting a quantity of chips in a perforated container or basket, which is revolved at high speed, with the result that the oil is flung through the perforations and reclaimed. One-third of the oil can be reclaimed by draining and another third by centrifuging, which is, in addition, a very quick and efficient process. The speed of revolution of the basket ranges from 500–1200 r.p.m.

Central Lubricating Systems.—Central lubricating systems supplying coolant to more than one machine are only adopted when a whole battery of machine tools is able to work with an identical coolant. Some prefer individual coolant distribution for each machine, because of the greater flexibility. Thus, while on one day six machines may be using lard oil, and thus be quite suitable for central lubrication from a common supply, on another occasion it may be necessary to have three running on lard oil and three on an emulsion. Thus, a central system would be less effective here.

Machines intermittently operated should not employ a coolant likely to cause rusting or corrosion during the period when they are not actually in service. This may mean that a non-corrosive cutting compound has to be substituted for a theoretically better soluble solution.

Lubricating Pumps.—The modern lathe has a small pump electrically driven which circulates the coolant from a reservoir located in the lathe trough, means being adopted to prevent the passage of chips, whether large or minute, into the main supply or the pump itself. There are simpler methods employed because of their low cost and convenience, but in general it can be said that the modern developments are all designed to give a higher degree of efficiency, economy, and stability in the supply of coolant.

Skin Infection.—Some attention should be paid to the risk of infection due to the use of a cutting compound. Certain compounds are particularly liable to cause septic wounds if they come into contact with slight abrasions or cuts in the skin of the operator. For this reason many makers of cutting compounds introduce into the composition of their products an antiseptic or disinfectant, usually a phenol or carbolic acid, and in choosing a proprietary lubricant it will be as well to ascertain if such a disinfectant is among the ingredients of which it is composed.

Another point to be borne in mind is that certain cutting fluids, when heated to too great a temperature, rapidly carbonise and produce a most obnoxious odour. Hence, care should be taken not to use for work generating great heat a fluid of this type, of which lard oil is an example when used pure.

CUTTING OILS

Organic	*Mineral*	*Blended*	
Lard oil (1) (3) Fish oil (3) Cotton-seed oil (2) Rape-seed oil (2) Turpentine Corn oil Linseed oil	Paraffin Machine oil	Organic oil + Mineral oil	Oil + Lithopone
	Used for	*Used for*	*Used for*
	Automatics Gear generation Reaming	Grinding (some) Tapping Turret lathe work Automatics Parting off Broaching Drilling Reaming Threading	Tapping Deep drawing
Used for	*On*		*On*
Tapping, threading, broaching, deep drilling,‡ milling, reaming, automatics	Aluminium alloys Free-cutting brasses* Magnesium alloys		Most metals
On	*Use*	*On*	*Use*
Aluminium alloys Tool steels* Stainless 18/8 steel† Soft steel Wrought iron (*for light work only*)	*Light machine oil	Steel Non-leaded brasses Aluminium alloys Magnesium alloys Copper	400 lb. dry lithopone 800 lb. talc 165 gal. heavy gear oil 70 gal. paraffin oil 450 lb. sulphur

* Lard oil and turpentine.
† Tapping, use white lead + tallow + linseed oil.
‡ Deep drilling of hard steel, use turpentine.
(1) Expensive.
(2) Liable to gum.
(3) Liable to carbonise at high temperature.


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EMULSIONS

Water+Oil +Alkali	*Water+Soap +Mineral Oil*	*Mineral Oil +Soap*	*Mineral Oil+ Sulphonated Oil*
Used for	*Used for*	*Used for*	*Used for*
Burnishing Drawing Stamping	Drilling Turning Parting off Boring Threading Milling Broaching Grinding Tapping	Drilling	Threading Tapping Gear cutting Broaching
On	*On*	*On*	*On*
Brass (1) High-carbon steel (2) Alloy steel (2) Low-carbon steel (2), (3) Zinc Aluminium alloys (4)	Low-carbon steel High-carbon steel Alloy steel Alloy cast iron	Wrought iron	Copper (1) High-carbon steel (2) Alloy steel (2) Low-carbon steel (3) High-nickel alloys Zinc (4)
Use	*Use*		*Use*
(1) 1 part sulphonated soluble oil, 10–20 parts water (2) *For burnishing:* 15·5 gal. clean oil 7·75 gal. denatured alcohol 79·25 gall. paraffin oil 3·75 gal. caustic soda 167·3 gal. water 441 lb. laloum powder 110 lb. Bentonite (3) *For drawing:* ¼ lb. deodorised fish-oil soap 1 gal. water (4) 1 part soluble oil 15–20 parts water	1 qt. soft soap 1 lb. carbonate of soda 1 qt. lard oil 10 gal. water ——— 27 gal. paraffin oil 4 gal. oleic acid 2 gal. denatured alcohol 1 gal. caustic soda solution 24 parts water to 1 part of above		(1) 1 part sulphonated oil, 10 parts light machine oil (2) 1 part sulphonated oil, 9 parts petroleum oil (3) 1 part sulphonated oil, 19 parts light petroleum oil (4) 1 part neutralised sulphonated oil, 14 parts water

Note.—Whilst aluminium can be machined dry, best results are obtained when a lubricant is used; a soluble oil gives good results, so also will paraffin, carbon oil, and lard oil—the latter for heavy cuts.

DRY CUTTING OPERATIONS

Threading	*Turning*	*Drilling*	*Tapping and Chucking*	*Reaming*
Brass Cast iron	Austenitic Manganese steel Babbit metal Copper Tool steel Soft steel Brass Cast iron	Brass Cast iron Austenitic Manganese steel Copper Babbit metal	Cast iron Brass Copper Babbit metal	Cast iron Brass Babbit metal

LUBRICANTS AND USES

For Copper	*For Steel*	*For Aluminium Alloys*
[illegible] crude petroleum oil [illegible] lard oil	50 per cent. lard oil 50 per cent. petroleum machine oil	10 parts paraffin* 1 part lard oil
3 parts machine oil 1 part lard oil	30 per cent. lard oil 70 per cent. machine oil	50 per cent. paraffin 40 per cent. lard oil 10 per cent. carbon tetrachloride
For Non-leaded Brasses	10–12 per cent. pure lard oil 88–90 per cent. neutral mineral oil	†75 per cent. low-viscosity petroleum oil 25 per cent. lard oil
75–90 per cent. machine oil 10–25 per cent. lard oil	1 part lard oil 3 parts petroleum oil	
	10 gal. lard oil 1 gal. paraffin	
	90 per cent. mineral oil 10 per cent. lard oil	

* For grinding. † For free machining.

Note.—Thorough mixing of the cutting emulsions is important, especially when mixing soluble oil with water. Emulsion should also be stable at all temperatures. Care should be taken to follow the instructions of the suppliers when the user mixes cutting compound in his own shop. Although plain water and soda-water mixture are still much used they have very little lubricating properties, and commercial cutting compounds are gradually taking their place.

IMPREGNATING POROUS NON-FERROUS CASTINGS

The use of Bakelite sealing fluid for the reclamation of non-ferrous pressure castings is now being employed by many foundries throughout the country with successful results. The use of this process is not put forward as a general method for correcting defective work. A sound casting is preferable to a reclaimed one.

Limitations.—The process is chiefly applied to porous non-ferrous castings in bronze, gunmetal, brass, light alloys, etc. It cannot be satisfactorily applied to alloys such as cast iron with equally satisfactory results, in view of the differences in the form of the porosity which occurs between ferrous and non-ferrous materials. Generally speaking, porosity in non-ferrous castings is of a much finer type than that which occurs in cast iron, and accordingly reclamation of the former can probably be more safely contemplated.

Degree of Porosity Permissible.—For overcoming porosity in castings two sealing mediums are available in this country, V.1845 and N.2106, supplied by Bakelite Ltd., 18, Grosvenor Gardens, London, S.W.1 (American equivalents are BV.1845 and BE.2106, supplied by Bakelite Corporation, 30, East 42nd Street, New York), and this section covers the use of these particular materials.

Bakelite V.1845 is a clear solution and is recommended for use in cases of fine porosity; whereas N.2106 is a solution containing a finely divided mineral filler and is employed when the porosity is more pronounced. It is not intended, nor desirable, on account of the relatively low strength of Bakelite, that it should be used for treating the grosser forms of casting defects, and it is suggested therefore that solution V.1845 should be adopted as standard and the use of N.2106 solution eliminated as far as possible.

The Bakelite sealing process has proved ideal for the treatment of intercrystalline porosity in non-ferrous castings caused by high pouring temperatures, inadequate feeding, or the presence of gas. Common sense will usually indicate whether there is a reasonable chance of salvaging a particular casting, and a useful guide in this direction can be obtained as follows:

(1) If, when putting on pressure during impregnation, the Bakelite solution comes out as a jet, the result will probably be a failure. If the solution oozes out as a bead, then the casting can probably be satisfactorily salvaged.

(2) If a casting is not rendered pressure-tight by one impregnation, it may be presumed that the porosity is excessive and in all but exceptional cases the casting should be scrapped.

The practice of reducing the pressure of the sealing solution to zero and allowing it to congeal at room temperature and then applying strapping around the outer periphery of the casting over the porous area with reapplication of pressure is not to be recommended.

Effect of Service Conditions.—It is claimed that when properly applied and treated the sealing material is stable under the majority of service conditions. It is quite unaffected by hot or cold fresh and sea water, steam up to a temperature of 205° C. (400° F.), and most chemical reagents. It is also resistant to hot oil up to 135° C. (275° F.) diethylene glycol petrol and other organic solvents. It is not affected by acids except those of a highly oxidising character, such as strong sulphuric acid or nitric acid. It is, however, attacked by strong hot caustic alkali.

Apart from the general statement given above, little other data seem to have been published on the effect of service conditions. A German paper on Refrigeration Technique (A. Rehbock, *Z.V.D.I.*, Vol. 86, No. 7/8, 21/2/1943) suggests that castings impregnated with plastic materials of the polyvinylchloride or polystyrol type are resistant to ammonia, but are affected by other cooling agents employed for refrigeration, such as methylchloride. It should be noted that the Bakelite solutions mentioned above are of the phenol-formaldehyde type and are much more stable in service than synthetic resins of the polyvinylchloride or polystyrol group. Bakelite is unaffected by all coolants used in refrigeration, including methylchloride.

Application of the Process.—In order to obtain satisfactory results it is important that the castings should be perfectly free from liquids used for previous pressure tests, such as water, paraffin, or oil. Castings which have been tested with water or paraffin can be readily dried out in a mould or core stove, keeping in mind that a temperature of approximately 285° C. (545° F.) is required thoroughly to vaporise paraffin. When heavy or mineral oil has been used for previous testing, its removal from the porous area is more difficult. Ordinary degreasing treatment without pressure is not really effective and probably best results are obtained by cleaning with Bakelite thinner S.5353, although even the effect of this cannot be guaranteed when the porosity is minute. Excess oil should be removed with dry waste or rags, and, if possible, the Bakelite thinner should preferably be injected under pressure, although it is appreciated that this may not always be convenient or practicable.

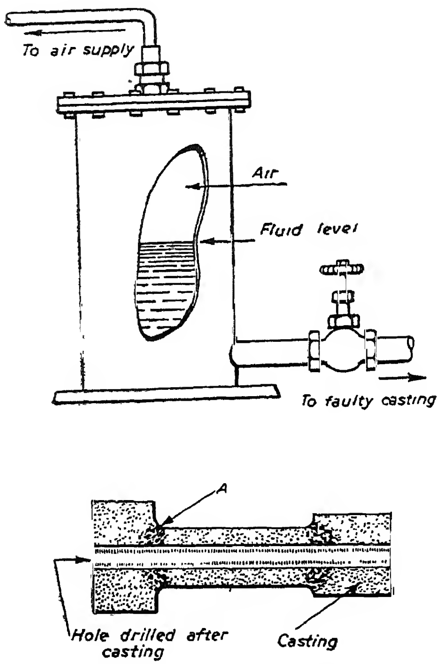


Fig. 1.—Method of impregnating porous castings with bakelite.

Two methods are available for impregnating the castings with the Bakelite solution V.1845. For the treatment of small castings a vacuum impregnation process has been suggested, in which the castings are placed in a suitable container, from which the air can be evacuated. When a suitable vacuum has been attained, the sealing solution is allowed to run in from a storage vessel until the castings are covered, after which pressure is exerted for a convenient time. This method has not been received very favourably by founders in this country, as it is more complicated than the second method about to be described, which utilises direct internal-pressure application of the sealing solution.

Recommended Method of Impregnating. — All exits on the casting must be closed except those to be used for filling the casting with the sealing solution and for removal of displaced air. Lead or synthetic rubber should be employed for packing washers on blank flanges used for "stopping-off" purposes, as ordinary packings containing rubber soon become tacky on contact with the sealing solution. If the casting has a large internal bore this may be partially filled with scrap metal in order to conserve sealing solution.

When the casting is filled, pressure is applied by means of a hand pump or by the use of compressed air as shown in Fig. 1. *The use of a hand pump is to be preferred,* as with compressed air most foundries will not have pressures available of over 100 lb. per sq. in., and in the majority of cases this is not sufficient to ensure thorough impregnation, which should be carried out at as high a pressure as is practicable, and, so far as non-ferrous castings are concerned, at not less

than 300 lb. per sq. in. Actually, best results are obtained by impregnating at or above the usual test pressure on the casting. The degree of pressure applied should preferably be high enough to force the Bakelite solution through the porous area to the outside of the casting.

The casting is now emptied and the excess sealing solution drained away into a suitable closed container for future use, and the casting lightly wiped with a cloth moistened with Bakelite thinner S.5353 where necessary. For castings of complicated internal form, a simple wiping operation may not be practicable, and a quick agitated immersion or flushing of the casting in or with the thinner solution might be considered as an alternative. This is advisable, because after stoving the hardened Bakelite adheres strongly, and is difficult to remove except by machining or hand-tool work. The thinner mentioned above can also be used for removing sealing solution from the hands of the operators, but if this is done it should be followed by washing with soap and hot water, with the subsequent application of lanoline or similar cosmetic preparation.

Polymerisation Procedure (Stoving).—The Bakelite sealing solution remaining within the porous area of the casting must now be "fixed" by polymerisation. This is conducted by placing the casting in a suitable well-ventilated stove at room temperature. Heat is then applied, so that during the first hour the casting is brought up to a temperature of about 85° C. (185° F.) and held for one hour. After the solvents are removed, the temperature is raised to about 110° C. (230° F.) for an hour, and finally raised to between 135° C. and 170° C. (275° F. and 340° F.) for a similar period. It is important to note that the castings should reach the above temperature, otherwise complete polymerisation of the plastic will not be effected. A thermometer or thermocouple should be fixed to the inner surface of the casting if possible, and the castings should be placed immediately adjacent to the hot end of the main stove pyrometer, if this is feasible. The above scheduled temperatures and times are not critical and are given only as a guide. A difference of 5° C. (9° F.) on the first two stages would be reasonable. The object of the slow initial stages is gradually to remove the solvents and prevent excessive disturbance or bubbling of the sealing solution within the porous area. It might also be noted that in the case of light alloy castings the subsequent heat-treatment operation can be satisfactorily employed to effect polymerisation of the Bakelite.

After the casting is cool, it is ready for the usual hydraulic tests.

It should be mentioned that consideration of the data collected indicates that all non-ferrous founders using the process have obtained satisfactory results. It would appear possible to reclaim between 50 per cent. and 70 per cent. of defective castings rejected due to leakage on the hydraulic test. Furthermore, so far as is known, all castings treated have proved satisfactory in service. One large non-ferrous foundry report that the process has been successfully applied to castings of the following types:

	Working Pressure lb. per sq. in.
Oil filters	100
Hydraulic cylinders	100–5000
Water heaters	100
Pressure vessels	100
Drying rollers	700
Pump bodies and cylinders	100–400
Valve bodies	up to 5500

This process has been used experimentally by several companies, and the following is typical of the experience of many. It is simple to apply, does not require extensive plant for its application, and would appear to be eminently satisfactory for the safe and permanent repair of porosity caused by interdendritic shrinkage in bronze castings.

Early experiments were made on gunmetal castings of B.S. 900/1 intentionally prepared to produce shrinkage by lack of feeding. The castings were cast solid in the form of a dumbbell, as shown in Fig. 1 (bottom), and run at the smaller end; they were machined all over with a ½-in. hole drilled right through the length. As was anticipated, out of thirty castings made, twenty-eight were porous on hydraulic

test of 400 p.s.i.: porosity was mainly in the neck "A." The castings were then treated by pumping in V.1845 Bakelite with a hand pump. Varying pressures were applied from 100 p.s.i. to 800 p.s.i., also the times under pressure were varied from 5 seconds to 10 minutes. In some castings Bakelite was forced out of the pores; in others this was not obvious. Curing was carried out in all cases at 300° F. under pyrometric control.

The twenty-eight castings were then subjected to a hydraulic test at 400 p.s.i., and four were still porous.

All castings impregnated at a pressure above 300 p.s.i. were sound, irrespective of their impregnating time, and the failures were:

(1)	Impregnated at	100	p.s.i. for	2	minutes.
(2)	,, ,,	200	,, ,,	2	,,
(3)	,, ,,	200	,, ,,	10	,,
(4)	,, ,,	300	,, ,,	5	,,

The failures were re-treated at 400 p.s.i. for one minute, cured, and all then passed the test.

Subsequent experience on more general lines has confirmed the above data that the time of treatment under pressure does not affect the result, and also that the curing temperature is not critical.

Whilst in the writer's experience it has never been necessary to impregnate more than twice to seal a casting, it would appear that even gross defects could be closed up by repeated applications of the process, and in consequence the following guide for operation has been drawn up:

(1) Impregnation should be carried out at as high a pressure as is practicable.

(2) If a casting is not rendered impermeable by one treatment, it is presumed that the porosity may be gross and the casting is scrapped.

(3) As far as possible, the Bakelite should not become mixed with water.

Filling for Blowholes in Castings.—Frequently holes due to trapped gases during the casting process will be found in unimportant places (from the strength point of view), which detract very much from the appearance of the casting. These holes may be filled by using a thick paste mixed with water and including the following ingredients: sal-ammoniac 2 parts, flowers of sulphur 1 part, iron filings or borings 80 parts.

An expanding alloy to fill holes in castings consists of lead 9 parts, antimony 2 parts, bismuth 1 part. This alloy should be melted and poured into the holes whilst the casting is warm.

A metal which will expand on cooling and which is useful for filling certain blowholes consists of 9 parts by weight of lead, 2 parts by weight of antimony, and 1 part by weight of bismuth.

OXIDISING ALUMINIUM

Anodic oxidisation of aluminium can be successfully carried out by the following methods:

Chromic-acid Method.—Three per cent. solution of chromic acid as the electrolyte. A carbon rod or a strip of stainless steel (the latter is preferable) as the cathode. The bath should be maintained at a temperature of 45° C., and for the first 15 minutes the voltage of the current is steadily raised to 40 volts, where it is maintained for 30 minutes. During the following 5 minutes it is raised to 50 volts, and kept at this voltage for a further 5 minutes.

Sulphuric-acid Process.—In this process a dilute solution of sulphuric acid forms the electrolyte and a strip of lead forms the cathode. The electrolysis is conducted at room temperature, and a steady current of from 10 to 20 amps. is passed for 30 minutes.

In order to obtain the best oxide films on aluminium it is essential that the metal should be well cleaned previously, especially when it is intended to colour the oxide film. This dyeing process should take place immediately the oxide film has been deposited. Remove the metal from the oxidising abth, wash it well, and immerse it in a 2 per cent. dye solution in the cold. For half an hour gradually raise the temperature of the dye bath to boiling-point, maintaining it at that temperature for a quarter of an hour, and finally wash the dyed metal coating in warm water. Any basic dyestuff may be used for the dyeing of oxide films prepared as above.

RECLAMATION OF WORN PARTS

The salvage of worn and over-machined and the treatment of new parts of machinery by electro-chemical deposition originated, and has been highly developed, in this country, where it has been carried out for some twenty-five years, latterly on an extensive scale. Various metals, such as iron and copper, have been employed for the purpose, but modern tendency is to concentrate on the use of nickel and chromium, which fulfil the great majority of requirements.

Adhesion of Deposited Materials

The importance of ensuring perfect adhesion between the basis metal and the deposit cannot be over-emphasised, as any dislodgement or separation of the two might have disastrous results in service.

This quality of the adhesion of electro deposits is due to forces of atomic attraction, and is obtained by chemical, not mechanical, preparation of the surface.

Owing to the high adhesive value, interrupted surfaces, such as splined or keyed shafts, may be processed, and subsequent machining carried out without danger of removing the deposited metal from the base. As no mechanical reduction of the surface of the component has to be carried out in order to ensure adhesion, the strength of the part to be treated is not affected.

The smoother the surface presented for deposition the better the adhesion. Again, as the process is a cold one there is no danger of distortion of, or damage to, the component under treatment.

It is not easy to carry out tests on the adhesion of chromium deposits, as the metal has comparatively poor cohesion, and is inclined to crumble under a severe pull. With nickel, however, such tests can readily be made and show very good results.

A typical test is one carried out at the National Physical Laboratory in 1929, when three nickel-coated steel and one solid-steel specimen were submitted to direct tension with results as follows :

Description of Specimen	*Failing Load in Tons*	*Maximum Shear Stress applied in Tons per Square Inch*
Nickel deposited	14·96	18·4
Nickel deposited	16·17	19·9
Nickel deposited	15·98	19·8
Solid steel	11·68	14·5

Fracture of the nickel-coated specimens occurred by shearing of the steel just inside the nickel coating, *and not by failure of the adhesion between the coating and the steel.*

The close similarity in the maximum shear stress applied to the three nickel-coated specimens is noteworthy.

The low failing load of the steel specimen is not readily accounted for, as all specimens were made from the same material.

Generally speaking, however, it has been found that the tensile properties of the basis metal are increased in proportion to the thickness of the deposit.

Choice of Materials

Nickel.—The selection of the most suitable material for the deposit is determined by the use to which the component has to be put and by the amount to be applied. In some cases a combination of nickel and chromium is recommended, as for example when a heavy deposit is required to make good a badly worn part, and where a hard surface is required. It is not generally advisable to apply

chromium in greater thicknesses than 0·008 in., so in the event of a greater amount of wear having to be dealt with it is customary to build up with nickel to a thickness that allows for the above maximum amount of chromium.

Nickel when deposited is a medium-hard substance. Its useful hardness can be taken to lie between 150 and 400 diamond, depending on the uses to which it is to be put.

As the hardness is increased the ultimate tensile strength is also increased, while the elongation is correspondingly reduced. Thus a nickel deposit having a diamond hardness of 170 may have an elongation of about 18 per cent., while a hardness of 280 will show an elongation in the neighbourhood of 12·5 per cent. The present tendency appears to be in the direction of harder deposits now that some of the earlier difficulties of obtaining sound and reliable deposits have been overcome.

On the other hand, if too high a degree of hardness is attained, machining becomes difficult and grinding is necessary.

Nickel provides excellent corrosion resistance and increases corrosion-fatigue endurance by some 67 per cent.

It has an excellent heat-resisting value, and when applied to a steel basis will protect the part against oxidisation at elevated temperatures. It will perform satisfactorily as a bearing material provided it is in contact with white metal and not too highly loaded. It should not be used as a bearing surface in contact with ferrous material.

From the salvage point of view, it has one outstanding advantage over any other material in that it provides the best resistance to fretting corrosion, or the corrosion of closely fitting metal surfaces when subject to vibration. This phenomenon is considered to be due to a process of molecular attrition possibly closely associated with fatigue effect. *Pairs in which nickel is one of the materials are subject relatively to the least corrosion,* while harder materials such as chromium are very unsatisfactory.

Hence, parts which are subject to driving or push fits, such as those pressed into housings or carrying ball-bearing seatings, are actually improved by nickel deposition.

Chromium.—Chromium is recommended where a hard, wear-resisting surface is required. As deposited, it has a diamond hardness reading of around 800–900. It is generally applied direct to the basis metal, without any intermediate under-coat, such as copper, though as has been stated above, where heavy wear has to be made good, a deposit of nickel should be applied first.

As chromium, owing to its structure, is inclined to crumble under heavy or shock loads, it should only be applied under exceptional conditions, in thicknesses exceeding 0·008 in.

In most instances, when this wear has been exceeded the part treated is worn below its bottom limit and would require retreatment in any case.

The chromium can then be removed chemically and a new surface applied.

Chromium possesses a unique quality of "slipperiness," or "unctuousness," which is determined by the nature and properties of the surface molecules. Owing to its high surface energy, the unsatisfied atomic linkages bend over and unite with the surrounding linkages, leaving only a relatively small proportion free to attract, or attach themselves to, those of an adjacent surface.

Hence, seizure, or "cold welding," is avoided. As chromium is non-wettable and will not absorb oil, a continuous flow of lubricant must be provided, or the bearing with which it is in contact must be capable of absorbing oil.

Chromium should not be run against chromium or nickel, and does not work well in light alloys.

The most suitable bearing material is white metal, followed by gunmetal or copper-lead alloys.

Where it is necessary to use steel against steel, the facing of one of the pairs in chromium has been found to prolong the useful life by ten times. Such cases occur for example in cam drives, metal pressing and drawing dies, and plugs. In the two latter cases, not only is "cold welding" avoided, but the product is also free from draw marks.

The importance of providing a high degree of surface finish to chromium after grinding cannot be overstressed.

When a rough surface is left there is a danger that the hard high points may cut into the bearing material, hence it should, where possible, be lapped or honed. When only a light deposit is applied, the basis metal should be highly polished, as any irregularities will be magnified in the chromium surface.

Economics of Salvage.—Certain articles are, owing to their low cost of production, not worth the cost of a salvage operation, nor are parts on which only a small amount of work has been expended, unless there is a time saving to be considered, as in the case of a heavy or elaborate forging.

When salvaging a worn or over-machined part the value of the material and labour should be set off against the deposition and post-deposition charges, plus the scrap value of the original material. It will be found that where the machining cost of the part which has to be reconditioned is high salvage will effect considerable economies, while at the same time a better corrosion-proof and wear-resisting surface is obtained.

In some instances of machine-shop errors in an expensive component an economy of 90 per cent. has been achieved.

Applications.—There are very few machine-using trades which cannot find a use for electro-chemical deposition as a means of salvage or in the provision of a surface superior to ferrous metal.

In the engineering industry reduction gear shafts are restored to size and "fretting corrosion" avoided by nickel deposition; worn piston and valve rods, pump shafts, compressor rods, gudgeon pins, fuel valves, etc., are treated after wear.

Paper-makers find that dry felt rolls, stuff chests, and wall-paper embossing rollers have a greatly extended life when processed in nickel or chromium.

In the printing trade, worn press cylinders are restored to size, and sharper and more durable surfaces provided on engraved rollers. Parts of hydraulic machinery, such as rams, when treated as salvage when worn, or preferably when new, have a greater freedom from packing troubles.

The makers and users of automobiles use the process for surfacing many new parts such as cam and rocker shafts and arms, shackle pins, and for restoring worn crankshafts, spline shafts, swivel pins, brake cam shafts, and other components.

Users of press and drawing tools have found an increase in the life of plugs, stalks, and dies as high as thirty times after treatment.

Examples of work done for tool rooms are gauges, spindles, arbors, and boring bars. These parts are usually treated in chromium, either as a salvage operation or when new. Their life is thus increased by as much as tenfold, as not only does chromium act as a non-corrosive surface but it has also the faculty of resisting the cutting action of swarf.

Limitations of Process.—Electro-chemical deposition is not capable of being used for filling up pits or cracks or as a jointing medium. Hence any porosities should be removed before the part is treated. Chromium has no value on cutting edges; in fact, it is weak and inclined to crumble when deposited on a right-angled surface. Thus all such edges should be removed and substituted by a chamfer or radius.

It is not practicable to attempt to apply coatings of uniformly even thickness. There is generally a "build up" or increase in diameter at the ends of a shaft, and when depositing in a rebate there is a deficiency at the apex of the angle. Hence it is recommended that where practicable as large a radius as possible be provided to ensure a uniform distribution of the deposit. When even surfaces are essential, as is the case with the majority of moving parts, it is necessary to carry out a post-deposition machining operation. In some cases, a thin deposit will provide the requisite resistance to wear or corrosion, and here a machining operation is not necessary. It must be borne in mind, however, that deposition tolerances are somewhat wide, and these have to be added to the original machining tolerances when considering final dimensions.

Preparation of Parts for Treatment

When incorrectly machined parts are to be salved, it is not necessary to increase the amount of the error so as to ensure a complete surface of the deposited

material, because even if the part is not finally machined concentrically with the deposit and some of the basis metal is exposed, the deposit is so blended in with the base that no "feather edge" is exposed and there is no danger of the coating peeling.

When, however, a worn part is under consideration, it is best to machine the part as a first operation so as to remove any roughness and to present as smooth a surface as possible, for, contrary to generally accepted ideas, the smoother the surface the better the adhesion.

General Remarks

To sum up, the outstanding features of electro-chemical deposition are that it is a cold process, hence there is no distortion of the part treated, and the composition of the alloy, if an alloy steel is under treatment, is not disturbed.

Perfect adhesion is obtained by atomic attraction and not by mechanical means; it is not necessary to weaken the component by reducing it so as to obtain this adhesion, or to apply a heavy deposit for this purpose, as "feather edges" are no drawback, and no dovetailing has to be done, as the deposit can be "faded out" at the ends.

It can be applied to localised areas without affecting the remainder of the part, and on interrupted surfaces.

The applied materials, nickel or chromium, are resistant to the corrosive action of the majority of media.

The work cannot be carried out on site, but must be transported to the factory carrying out the process, and weight handled and area treated are limited to those of the operating concern.

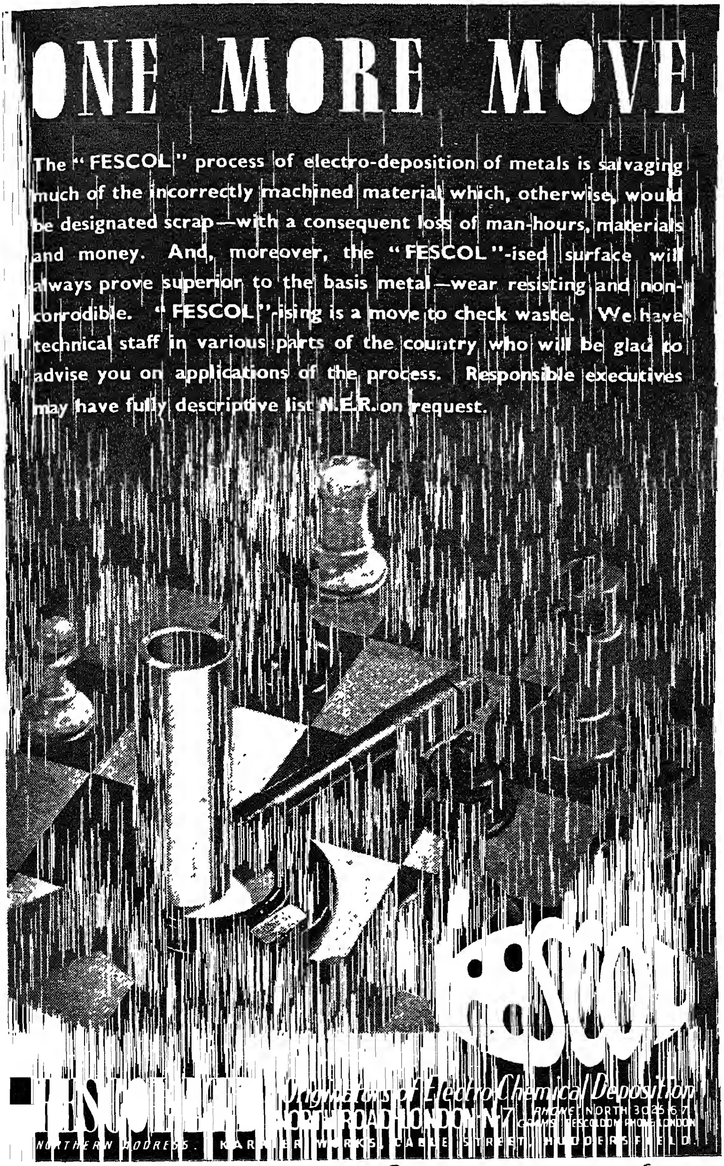
Facilities are, however, available in this country for handling shafts up to 20 ft. long and weighing 6 tons.

RECLAMATION BY METAL SPRAYING

In cases of wear on lubricated bearing surfaces the metal-spraying process may be used for the reclamation of the worn parts. It is important to realise that this process will not add strength to the reclaimed part, and therefore it is essential that the unit must have sufficient residual strength for further service. This having been ascertained, the process can be used to give a surface which will, under lubricated conditions, give longer life than the original part. This is due to the fact that the sprayed deposits of the metals of high melting-point are somewhat porous and will hold oil, so that the oil film on the lubricated part is maintained for very long periods.

In tests that have been carried out on crankshafts in actual engines, it was found that if the oil supply was cut off the bearing seized in two hours on a new shaft, but seizure came about only slowly after a period of twenty-two hours on a shaft built up by metal spraying. The process is particularly useful for all types of shafts, whether rotating at high or low speed, and for the crankshafts of petrol and diesel engines. In the case of steel shafts it is usual to deposit medium-carbon steel, high-carbon steel or stainless steel, and for bronze shafts a coating of phosphor bronze is used. The hardness of the deposited metal does not appear to have very much effect on the service life.

Method of Depositing Metal.—The metal is deposited by means of the wire-spraying pistol, which is a small tool weighing from 3½ to 4 lb. that can either be used as a hand tool or be fastened to the slide-rest of a lathe. All pistols for spraying wire consist of three different units mounted in one small case. One unit is a nozzle through which the wire passes down a central tube. Around this central tube is arranged a fluted annular space through which is fed a mixture of oxygen and a combustible gas under pressure. The mixing is effected in a mixing chamber located at the back of the nozzle. If no other arrangement was made the gases when ignited would melt the wire and drops of molten metal would be formed, but around the gas nozzle are arranged annular fluted grooves which carry compressed air at a predetermined angle, and this by its injection effect pulls off the molten metal continuously as it is formed and sends it forward as a fine spray.


ONE MORE MOVE
The "FESCOL" process of electro-deposition of metals is salvaging much of the incorrectly machined material which, otherwise, would be designated scrap—with a consequent loss of man-hours, materials and money. And, moreover, the "FESCOL"-ised surface will always prove superior to the basis metal—wear resisting and non-corrodible. "FESCOL"-ising is a move to check waste. We have technical staff in various parts of the country who will be glad to advise you on applications of the process. Responsible executives may have fully descriptive list N.E.R. on request.
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A very important part of the tool forming the second unit is the wire feed mechanism, and this is actuated by an air turbine driven by the compressed-air stream. This turbine is very light and normally rotates at about 20,000 revs. per minute. The shaft of the turbine actuates a number of gears which reduce

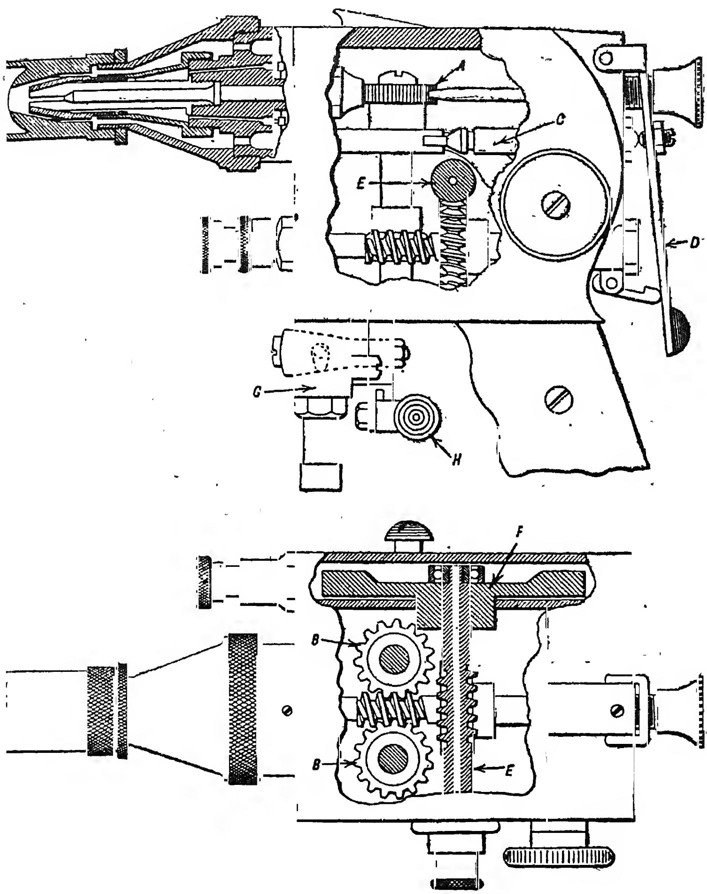

Fig. 1.—The metal-spraying pistol.

the speed and turn two rollers which grip the wire and make it travel through the nozzle at a steady speed controlled by a valve.

The third unit is the valve through which the feeds to the pistol are admitted. This valve may be a single plug with three ports or, what is more usual, three small plugs actuated by one control. The feeds to the pistol are oxygen from cylinders,

used at 20–30 lb. pressure through a suitable reducing regulator, the volume of oxygen used per hour being between 20 and 30 cu. ft. The second feed is a combustible gas which must have a calorific power of over 450 B.Th.U. The gas is under pressure, and may be hydrogen, dissolved acetylene, propane, or coal gas. Pressures varying between 20 and 30 lb. per sq. in. are used, and the volume required is between 20 and 40 cu. ft. of free gas per hour. The third feed is compressed air used at pressures between 40 and 60 lb. per sq. in., the volume required being 15–30 cu. ft. of free air per minute. At the working distance from the nozzle, that is, about 4 in., the temperature of the spray is about 150° C. at a maximum, and therefore the process may be regarded as cold.

Preparation.—Before the deposit is applied it is necessary for the surface to be roughened and cleaned, and there are three methods of carrying out this preparation:

(1) The surface is grit blasted at between 40 and 60 lb. pressure with angular steel grit, Grade D. On no account must ball shot be used.

(2) The surface of the shaft is given a rough screw thread of 20–28 threads to the inch, with a depth of about 0·030 in. The thread should be as rough as

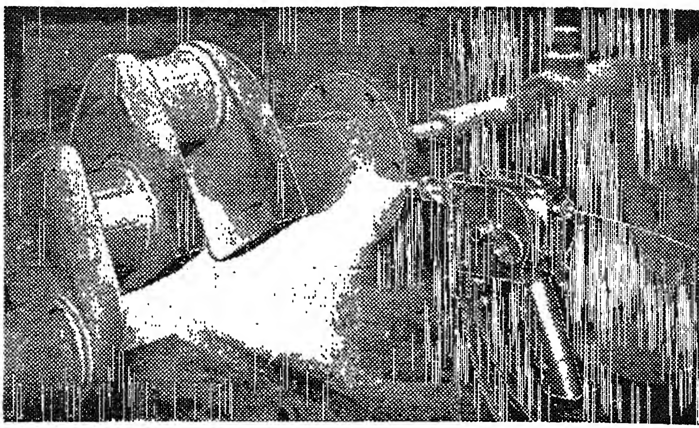

Fig. 2.—A worn crankshaft being built up by metal spraying.

possible and the surface left must be free from lubricant and moisture and, if dirty, must be degreased with trichlorethylene. The rough threading will then accept the deposit quite satisfactorily. This method should not be adopted if weakening of the shaft is likely to result.

(3) The third method, recently introduced in America, is known as Fuse-bond, in which case roughnesses are made by local arcing at comparatively low voltage from metal wires.

The second method is preferable in the ordinary machine shop, as the threading, spraying, and final grinding can be done on one lathe. It is important that the thickness of the deposit as finally ground should not be less than 0·015 in.

The work is prepared as previously stated and the deposit is applied direct to the prepared surface, the pistol usually being mounted on the slide-rest of the lathe. When the work of depositing is started it should be continuous and there should be no breaks. It is as well in the case of rough turning to slightly undercut the end threads in order to give a better key. It is important, especially when using low-carbon steel, that the oxygen content of the flame be kept as low as possible, and it is also essential in the case of small jobs which are likely to heat up to 150° C. that they should be kept as cool as possible by blowing a jet of com-

pressed air on to the work. The deposit will have a matt surface and should be deposited 0·010 in. on radius over the required thickness.

Although in the case of low-carbon steels the deposit can be turned down to final size, it is always advisable to grind back to size if at all possible. There are no special precautions about grinding sprayed metal, except that a vitrified bauxite wheel of medium bond should be used. The wheel is apt to glaze more quickly on sprayed metal than when grinding ordinary steel. If grinding is out of the question, turning can sometimes be achieved by running the work at a

Fig. 3.—Grinding the built-up part to size.

comparatively low surface speed, 70 ft. per minute, and using a well-sharpened tungsten-carbide tool taking very light cuts during the turning.

Before the work is put into service it is quite usual to let it remain in oil for about twelve hours; this ensures that there is sufficient lubricant in the first stages of use.

While these remarks apply to shafts generally, it is possible to build up flat surfaces and the internal surfaces of bores; but these require special technique, and it is advisable in such cases to have the work done by a firm with experience.

Metal spraying is much faster than welding or electro-chemical deposition, as much as 10 lb. steel per hour being deposited without risk of heat distortion or damage by acid contamination. It is employed on such vital parts as ships' propeller shafts and auxiliary machinery, and is generally accepted as a comparatively simple method of reclaiming worn parts, involving very little technical knowledge beyond a true understanding of its limitations and the appropriate method of preparing surfaces to give the maximum bond-strength.

Each of the processes dealt with in this section has been successfully applied to the renovation of snap, plug, and other gauges, and the process can be repeated indefinitely.

FACTORY LIGHTING

Introductory.—Advances in recent years in the development of light sources and in the science and technique of illuminating engineering have made possible great improvements in methods of factory lighting. Improvements in lamp efficiency combined with steadily falling costs of power have made far higher illumination levels economically justifiable; while the wide variety of light sources available, some of small area and high brightness, others of large area and low brightness, have made it possible to provide light of a quality suitable for almost every purpose. To-day lighting is recognised as a production tool, and as with any other such tool its value must be judged far more by the benefits that it confers than by the money it costs. Improvements in artificial lighting have increased production, and examples are given in the following table:

Type of Work Done	*Illumination*		*Increase in Production*
	Original F.C.	*Present F.C.*	*Per cent.*
General engineering	6	16	9
Woodworking	2·5	8	25
Weaving worsted	13·3	29	5·3
Fine engineering and rubber-leather products	4–6	12–20	15
Thread winding and finishing ..	3–5	15	10
Machine sewing and cutting-out tables	Low and very uneven	15–20	25

They reduce scrap and accidents; improve general health of workpeople and reduce absenteeism; enable better use to be made of available floor space; facilitate supervision; and facilitate cleanliness.

Requirements for Good Lighting.—The essential requirements for good lighting are: (1) sufficient quantity of light, and (2) suitable quality.

Quantity of Illumination.—The unit of quantity of illumination is the foot-candle (equivalent to the illumination falling on a surface every part of which is distant 1 ft. from a source equivalent to one standard candle). The generally accepted standard for desirable illumination values in this country is the I.E.S. Code. This code gives the following basic scale:

Recommended Foot-candle Value	*Class of Task*
(1) Above 50..	Precision work to a high degree of accuracy; tasks requiring rapid discrimination; displays.
(2) 25–50 ..	Severe and prolonged visual tasks; discrimination or inspection of fine details of low contrast.
(3) 15–25 ..	Prolonged critical visual tasks, such as proof-reading, fine assembling, and fine machine work.
(4) 10–15 ..	Visual tasks, such as medium machine and benchwork and sustained reading.
(5) 6–10 ..	Less exacting visual tasks, such as casual reading and large assembly work.
(6) 4–6 ..	Work of simple character not involving close attention to fine detail.
(7) 2–4 ..	Casual observation where no specific work is performed.

Published with this code (obtainable from the Illuminating Engineering Society, 32, Victoria Street, S.W.1) is a schedule of typical industrial and commercial operations classified in relation to the illumination range in which they fall.

A similar schedule is published by the Electric Lamp Manufacturers' Association in their handbook *Illumination Design Data* (obtainable from the Lighting Service Bureau, 2, Savoy Hill, W.C.2).

In order to gauge the illumination for any process not scheduled, it is customary to compare it with a generally similar process in the schedule. For this purpose it is necessary to be able to recognise those factors which affect illumination requirements so that a suitable comparison can be made. These factors are:

(1) Size of detail that it is required to see. Small objects require more light than large ones.

(2) Contrast between object to be seen and its background. Low contrast requires more light.

(3) Dark objects require more light than light ones.

(4) Moving objects require more light than stationary ones.

Under all circumstances any place in which persons are working for long periods requires a certain minimum amount of illumination for welfare. This illumination should generally not be lower than 6 f.c.

Quality of Light.—For good lighting light must be of suitable quality as well as sufficient in quantity. The principal requirements are: absence of glare, absence of excessive shadow, correct distribution at the working point, and adequate illumination on the background.

Absence of Glare.—To avoid direct glare brightness of all light sources within the normal field of vision should be limited. The normal field of vision is regarded as anywhere below a line 20 degrees above the horizontal from the eye. Ten candles per square inch is recognised as the permissible limit of brightness for direct-lighting reflectors mounted less than 16 ft. above floor level, and 5 candles per square inch for diffusing glass fittings. It is desirable, however, generally to keep brightness well below this level, and 2–3 candles per square inch can be taken as a good working limit, particularly if fittings are mounted low down, e.g. below 8 ft. from floor level.

Where highly polished and glossy articles are present care must also be taken to avoid reflected glare. In such circumstances the brightness of fittings must be limited over the whole of the lower part of the fittings.

Absence of Shadow and Suitable Distribution.—This can only be assured by correct choice and placing of fittings. To this end it is very necessary to analyse carefully the seeing task, not only to discover exactly what detail it is required to see, but also to determine how it is best seen, e.g. by deliberate use of patches of high brightness or by the use of shadow to emphasise texture, etc. To ensure absence of excess shadow, fittings should never be spaced too far apart. Guidance as to suitable spacing height ratios for various types of fittings will be found in makers' catalogues, but for general lighting it is undesirable to exceed spacing height ratios of $1\frac{1}{2}:1$.

Adequate Illumination Background.—Lighting must not only provide means to see the work but must also create a cheerful and pleasing effect. The importance of this aspect has also been fully proved in the black-out. To this end, not only must there be adequate light on all parts of the working plane, but a reasonable amount of brightness must be imparted to walls and ceilings. This means, in the first place, seeing that they are light in colour and are maintained in reasonably clean condition, and secondly seeing that a certain amount of light reaches them.

Statutory Regulations for Lighting.—Ministry of Labour Regulations for all factories working more than 48 hours a week (S.R. & O., No. 94, 1941) call for the installation of lighting that goes a long way towards meeting some of the requirements for quantity and quality listed above. The principal clauses of these regulations are:

"2. (*a*) The general illumination over those interior parts of the factory where persons are regularly employed shall not be less than 6 f.c. measured in the horizontal plane at a level of 3 ft. above the floor:

"Provided that in any such parts in which the mounting height of the light

sources for general illumination necessarily exceeds 25 ft. measured from the floor or where the structure of the room or the position of construction of the fixed machinery or plant prevents the uniform attainment of this standard, the general illumination at the said level shall be not less than 2 f.c., and where work is actually being done the illumination shall be not less than 6 f.c. or the greatest reasonably practicable illumination below 6 f.c.

"(*b*) The illumination over all other interior parts of the factory over which persons employed pass shall when and where a person is passing be not less than 0·5 f.c. measured at floor level.

"(*c*) The standard specified in this regulation shall be without prejudice to the provision of any additional illumination required to render the lighting sufficient and suitable for the nature of the work.

"3. (*a*) Where any source of artificial light in the factory is less than 16 ft. above floor level, no part of the source or of the lighting fitting having a brightness greater than 10 candles per square inch shall be visible to persons whilst normally employed within 100 ft. of the source, except where the angle of elevation from the eye to the source or part of the fitting as the case may be exceeds 20 degrees.

"(*b*) Any local light, that is to say an artificial light designed to illuminate particularly the area or part of the area of work of a single operative or small group of operatives working near each other, shall be provided with a suitable shade of opaque material to prevent glare or with other effective means by which the light source is complely screened from the eyes of every person employed at a normal working place, or shall be so placed that no such person is exposed to glare therefrom.

"(*c*) So far as reasonably practicable, arrangements shall be made, by suitable screening or placing or other effective method, to prevent discomfort or injury by the reflection of light from smooth or polished surfaces into the eyes of the worker.

"4. Adequate measures shall be taken, so far as reasonably practicable, to prevent the formation of shadows which cause eyestrain or risk of accident to any person employed."

It will be noted that the requirement of 6-f.c. minimum illumination is "without prejudice to the provision of any additional illumination required to render the lighting sufficient and suitable for the nature of the work." In other words, it is a requirement for amenity and welfare to be increased wherever the nature of the work demands it. In their report, on which these regulations are based, the Departmental Committee on Factory Lighting recommend the adoption of the I.E.S. Code values for all tasks.

It will also be noted that the illumination requirements are for a maintained service value and do not refer to initial installed illumination only. In practice illumination values drop considerably after installation on account of dust and dirt on fittings and lamps, depreciation of decorations, and ageing of lamps. An allowance of 30 per cent. is normally made, and is found by no means excessive under average conditions of maintenance. Far greater drops in illumination occur if regular maintenance is not arranged. If surroundings are very dirty or fittings are relatively inaccessible and therefore not likely to be cleaned frequently, bigger allowance should be made. The allowance of 30 per cent. given above means that installations should be designed to give 40 per cent. higher values when first switched on. This is described as allowing a depreciation factor of 1·4.

Light Sources.—Electric-light sources in general use are mainly of three types, namely, incandescent tungsten-filament lamps, electric-discharge lamps of high-pressure mercury and sodium types, and low-pressure mercury fluorescent tubular lamps. The main practical differences between these lamps lie in their efficiencies, colour-rendering properties, and the costs involved in their installation.

Tungsten Lamps.—Tungsten general lighting service lamps are available in wattage ratings from 15 to 1,500. Their colour rendering is quite good, with an excess in the red end of the spectrum, as a result of which red and yellow colours are over-emphasised and blues are dulled. Their initial cost is relatively low, and no special gear is required for their operation. Compared to electric-discharge lamps their efficiencies, varying from about 10 to 20 lumens per watt, are low.

Electric-discharge Lamps, H.P.M.V. and Sodium.—High-pressure mercury lamps in ratings from 80 to 400 watts have much higher efficiencies up to


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45 lumens per watt, but the light is very deficient in red rays, with the result that colour rendering at the red end of the spectrum is very bad. Fluorescent powder-coated high-pressure mercury lamps give slightly better colour rendering, but one still markedly deficient in red in comparison with daylight colours. Sodium lamps 45 to 140 watts have even higher efficiencies up to 65 lumens per watt, but they have practically no power to render colours, the light being a monochromatic yellow.

All types of electric-discharge lamps (including the fluorescent tubular lamps described below) are appreciably higher in initial cost than tungsten lamps of equivalent light output, and all involve the use of chokes or similar current limiting devices for their operation. Power-factor correction condensers are also normally installed and other gear may sometimes be necessary. The capital cost of a discharge-lamp installation will, therefore, always be substantially higher than a corresponding incandescent-lamp installation. On the other hand, the lamps have longer life, and this, combined with the savings in current cost, will usually pay off the extra capital cost over a period, varying according to the particular lamp involved and the prices ruling for current.

Fluorescent Tubular Lamps.—Low-pressure mercury fluorescent tubular lamps are the most recent addition to the range of lamps suitable for general lighting purposes, and have such outstanding qualities that they deserve special consideration. There qualities are :

(1) Large source area, which makes for soft and relatively shadowless lighting.

(2) Low surface brightness, which minimises risk of glare either direct or reflected.

(3) Controlled colour of light, making almost perfect daylight colour rendering possible, or providing warmer white light for more decorative purposes.

(4) High-efficiency equivalent to over twice that of equivalently rated tungsten lamps.

(5) Low radiant-heat emission approximately one-quarter that of tungsten lamps of equal light output.

All these qualities combined in a single lamp make them ideal for most lighting purposes, except where it is desired to concentrate light into a narrow beam. The large source area makes the tubular lamp unsuitable for this purpose.

Fluorescent tubular lamps for use on mains voltage are at present available in only one wattage rating, 80 watts, 5 ft. long, and in two colours, one almost equivalent to daylight and the other a warmer tone, but still with very good colour-rendering properties. Similar tubes can also be obtained for high-voltage operation. The latter can be obtained in a wide variety of colours and can be bent to requirements, thus making a tailor-made job possible.

Full details of rating and light output, voltage ranges, etc., can be found in lamp manufacturers' catalogues.

Lighting Systems.—Lighting systems can be designed either to light the whole area of a shop to a relatively even standard of illumination (general lighting) or to give light of special quality and illumination value at particular working points. Frequently the latter method is combined with the former in the form of local lighting.

General Lighting.—The advantage of general lighting planned in relation to an area is that it permits work to be carried out with reasonable efficiency at any position in the area, and is therefore particularly suitable when there are no fixed working positions or when alterations to layout are likely to be made at frequent intervals. General lighting can alternatively be planned in relation to fixed working positions, the layout still remaining symmetrical and ensuring relatively even illumination over the whole area, but being so planned that light comes to each fixed working place predominantly from the most favourable angle.

For general lighting, fittings having a symmetrical light distribution are usually employed. The best known of these for factory use are the standard dispersive direct-lighting reflectors to B.S.S. 232, for use with tungsten-filament lamps, and corresponding white-enamel trough reflectors for use with fluorescent tubular lamps.

Where there is risk of reflected glare off the work, the latter have special qualities, but if tungsten lamps are to be employed, industrial diffusing reflectors should be substituted for the standard dispersive type. Alternatively, where walls and

ceiling are light in colour and ceilings are not too high, opal glass diffusing fittings may be used. Where direct-lighting fittings are used, it is important not to forget the need for a reasonable amount of light reaching walls and ceilings, so as to avoid an unpleasant "tunnel effect." Some types of reflector, particularly those designed for use with fluorescent tubular lamps, have openings at the top to allow the emission of light for this purpose.

Fittings Layout for General Lighting.—In order to attain the desired degree of uniformity, the spacing between fittings for general lighting purposes must not be excessive. The maximum permissible spacing in relation to mounting height depends upon the light distribution of the particular fitting selected, and this will normally be indicated in the manufacturers' catalogues. Most of the fittings mentioned above are designed for a spacing height ratio of $1\frac{1}{2}$: 1, i.e. the distance between fittings must not exceed one and a half times their height above the working plane. The latter is usually reckoned as 3 ft. above the floor unless special considerations obviously indicate some other level. Where the work is mainly on the horizontal plane, it is unwise to use fittings designed for wider spacing height ratios than $1\frac{1}{2}$: 1, as there will be a danger of heavy shadows at intermediate points between fittings. Where, however, illumination is specially desirable on vertical surfaces, fittings designed for wider spacing may be appropriate. In general, recommended spacing-height ratios should never be exceeded, but closer spacing may be adopted with advantage. It will be seen from the above that mounting height is a controlling factor in relation to the spacing of fittings, and considerations of available mounting height in relation to the length and breadth of the area to be lit and convenient suspension positions will be major factors in determining the actual layout of fittings over the area. It is advantageous to mount fittings up to the full height available unless the latter is abnormally great in relation to the width. Contrary to popular belief, increased mounting height of fittings in a multi-lamp general lighting installation makes very little difference to the illumination on the working plane. On the other hand, increased height reduces risks of both direct and reflected glare, and either enables wider spacings to be adopted (thus reducing the number of points) or for a given number of points ensures better overlap of light.

To determine lamp ratings the following formula applies :

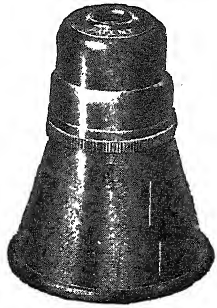
$$\text{Total required lumens} = \frac{(\text{floor area in sq. ft.}) \times (\text{required illumination in f.c.}) \times (\text{depreciation factor})}{(\text{coefficient of utilisation})}.$$

The coefficient of utilisation is a figure which takes into account all those conditions which affect the amount of light which reaches the working plane, notably the overall luminous efficiency and light distribution of the fitting, the reflection factors of walls and ceilings and the room index which allows for the relation between the proposed mounting height and the length and breadth of the room.

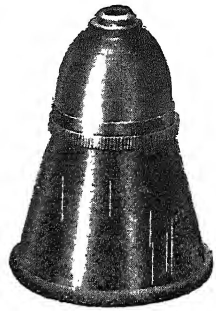
Local and Localised Lighting.—For determining illumination under installations designed to give special illumination over limited areas, as distinct from general lighting, other techniques must be employed. Such systems are usually designed either to light a strictly limited area with very little spread of light (local lighting) or to light rather larger areas (e.g. a continuous run of assembly bench or line of machines) with a spread of light that gives a lower, but none-the-less sufficient, amount of light for non-working spaces between such areas. This system is usually referred to as "localised lighting," and has come largely into vogue since the introduction of fluorescent tubular sources. While, provided the distance between working places is not too great, the latter system may be used without any additional general lighting, "local lighting" should only be used as a supplement and never as the sole form of lighting.

To determine illumination values under these systems, the exact light distribution of the fittings must be known. This light distribution is usually given in manufacturers' catalogues by means of polar curves. It is important to realise that these curves only indicate the directions in which light is emitted from the fittings, and the relative intensity in each direction, and should not be employed as a guide to overall efficiency, for which purpose they may be very misleading. Where a single fitting is employed for each workplace, as is usually the case with

" *Lincoln*" *for Ordinary Twin Flex*



" *Standard*" *for C.T.S. or Workshop Flex*



" *Standard* " *for Ordinary Twin Flex*

"Home Office" Lampholders

CRABTREE "Home Office" Lampholders are moulded in lustrous "Jacelite" shockproof material and comply implicitly with British Home Office requirements for factory use. They embody a substantial metal reinforcing liner, and the shade-carrier arrangement consists of a protective skirt which effectively prevents all possibility of contact with lamp cap or liner during either insertion or withdrawal of the lamp.

Various types of Crabtree "Home Office" Lampholders are included in the range and all are offered in 2- and 3-slot patterns, the latter being suitable for use with mercury-vapour discharge lamps with caps made to British Standard Specification No. 469/1932.

While the employment of this type of accessory is particularly recommended for industrial service, the high degree of safety ensured by its design makes the Crabtree "Home Office" Lampholder eminently suitable for all locations where the employment of metal lampholders is not desirable.

CRABTREE

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local lighting, the illumination can be determined direct from the candle-power reading on the polar curves, the illumination in foot-candles being equal to the candle-power of the fitting in the given direction divided by the square of the distance (in feet) of the fitting from the work. Where the light strikes the work at an angle, the result so found must be further multiplied by the cosine of that angle. Local lighting is generally used either to provide high values of illumination at special points or to give a directional light component where such is required for a special purpose, e.g. to emphasise texture or to penetrate to places which, owing to obstruction, general lighting cannot reach.

Where "localised lighting" is provided by a number of fittings designed to build up illumination over a larger but still limited area, iso foot-candle diagrams must be employed. These diagrams, prepared in relation to a fitting at a given mounting height above the work, show the different zones of equal illumination at varying distances from the point on the working plane immediately below the fitting. By superimposing such curves with appropriate overlap, the built-up illumination with any number of fittings at any agreed spacing can be found.

Maintenance.—In speaking of the depreciation factor, mention has been made of the allowance necessary to compensate for deterioration in lamp and fitting performance and the depreciation of decorations under normal service. It cannot be over-emphasised, however, that this factor only allows for the drop in illumination which will occur almost inevitably, even if fittings are regularly cleaned at reasonable intervals, lamps replaced at the end of their rated lives, and decorations maintained in a clean condition. If these precautions are not taken far greater drops in illumination are likely to take place, and users may well find themselves obtaining less than 50 per cent. of the service (as distinct from initial) illumination which the installation was designed to give. Where specially dirty conditions prevail a greater initial allowance should be made unless very constant cleaning is possible. Equally where fittings have to be mounted very high up in a murky atmosphere (e.g. a foundry), allowance must be made for light absorption by the atmosphere. It is impossible to suggest figures for such allowances, which depend upon the circumstances, but a preliminary test with new fittings will give some indication of the provision that should be made. Regular checking of illumination values with an illumination meter is very desirable, as a drop in illumination where it takes place gradually over a period of months may easily pass unnoticed under casual observation. Suitable pocket illumination meters of the photo-electric type can be obtained, but it is important to have the calibration checked periodically, as they are liable to considerable errors.

Psychological Benefits of Good Lighting.—Experience in blacked-out factories has emphasised the very great importance of the psychological benefits which good lighting can confer. The function of lighting is not only to give the necessary facilities of vision but also to create a cheerful and pleasant working atmosphere. To this end more and more attention is being paid to the possibilities of colour in relation to lighting. Light walls and light ceilings will increase the amount of light on the working plane because of the amount of light which they reflect, but this is a minor advantage compared with the effect which they have in brightening the whole scene and creating the right atmosphere. The use, however, of light colour can be usefully carried far beyond the realm of walls and ceilings. Light colours on machine bases and all fixed gear go a long way towards improving atmosphere, an improvement which is all the greater if colours are varied and not kept alike. Light floors will also be beneficial. These remarks apply just as much to places which are inherently dirty as to those which are relatively clean. Dirty light colours may show the dust more, but they will still be brighter than dirty dark colours.

It has been found that beneficial results have accrued when attention has been paid to the colouring of machine tools as well as the walls of the factory. Colours which absorb light should be avoided, as also should depressing colours.

There is a tendency among machine-tool manufacturers to break away from the drab battleship grey or raw-casting finish of previous years. A machine shop can be made bright without being bizarre.

TOOTHED GEARING

Notation

(All linear dimensions expressed in inches)

a = Addendum of pinion (or worm).
A = Addendum of wheel.
b = Dedendum of pinion (or worm).
B = Dedendum of wheel.
c = Clearance.
C = Centre distance or (for bevel gears) cone distance.
d = Pitch diameter of pinion or worm.
D = Pitch diameter of wheel.
f = Facewidth.
G = Throat diameter of wormwheel.
i = Root diameter of pinion or worm.
I = Root diameter of wheel.
j = Tip diameter of pinion or worm.
J = Tip diameter of wheel.
L = Lead = axial pitch × number of teeth (or threads).
m = Module $\left(\text{for worm gears } m = \dfrac{\text{Axial pitch of worm}}{\pi}\right)$.
M = Torque on pinion or worm (lb.-in.).
p = Pitch.
P = Diametral pitch.
q = Diameter quotient (worm) $= \dfrac{d}{m}$.
R = Velocity ratio = T/t.
$R_1 = \dfrac{T \sec \theta w}{t \sec \theta p}$ (equal to T/t for spur or helical gears).
s = Rubbing speed factor.
t = Number of teeth in pinion or threads in worm.
T = Number of teeth in wormwheel.
U = Allowable wormwheel torque.
V = $(\sec \theta_p)^{0.8}$.
Z = Material factor.
θ = Pitch angle.
λ = Lead angle.
ρ = Root angle.
σ = Helix angle.
Σ = Angle between shafts.
ϕ = Face angle.
ψ = Pressure angle.

Suffixes.

a refers to axial section of gear.
n refers to normal section of tooth.
t refers to transverse section of gear.
p refers to pinion (or worm).
w refers to wheel.

A "transverse force" acts in a direction perpendicular to the centre line of the gear.

General.—Formulæ given here apply to gears having a normal pressure angle of 20 degrees. Some of them do not necessarily apply if the pressure angle is less than 20 degrees.

TABLE I.—RECOMMENDED NUMBER OF TEETH IN PINION (or THREADS IN WORM)

	Ratio	1	2	3	4	5	6	8	10 to 15	15 to 25	25 to 40	Over 40
Spur and helical	General ..	50	40	32	28	26	24	22	20	—	—	—
	C.I. wheel ..	38	30	24	21	20	18	17	15	—	—	—
	Casehardened steel wheel and pinion..	25	20	16	14	13	12	11	10	—	—	—
Spiral ..	.. ..	25	21	17	13	11	9	7	—	—	—	—
Bevel	General ..	40	30	22	18	14	—	—	—	—	—	—
	C.I. wheel ..	30	24	19	16	13	—	—	—	—	—	—
	Casehardened steel wheel and pinion..	20	15	12	11	9	—	—	—	—	—	—
Worm ..	.. ..	—	—	10	8	7	6	5	4	3	2	1

Formulæ

$$p = \frac{\pi}{P} = \pi m.$$

Spur Gears (see Fig. 1):

$$C = \tfrac{1}{2}(d + D).$$

$$p = \frac{2\pi C}{T + t}.$$

$$d = \frac{tp}{\pi} = \frac{t}{P}.$$

$$a = \frac{1}{P}\left(1\cdot4 - \frac{0\cdot4}{R}\right).$$

$$b = \frac{1}{P}\left(0\cdot85 + \frac{0\cdot4}{R}\right).$$

$$c = \frac{0\cdot25}{P}.$$

$$i = d - 2b.$$

$$j = d + 2a.$$

$$\text{Transverse force} = \frac{2M}{d}\sec\psi_t.$$

$$P = \frac{T + t}{2C}.$$

$$D = \frac{Tp}{\pi} = \frac{T}{P}.$$

$$A = \frac{1}{P}\left(0\cdot6 + \frac{0\cdot4}{R}\right).$$

$$B = \frac{1}{P}\left(1\cdot65 - \frac{0\cdot4}{R}\right).$$

$$I = D - 2B.$$

$$J = D + 2A.$$

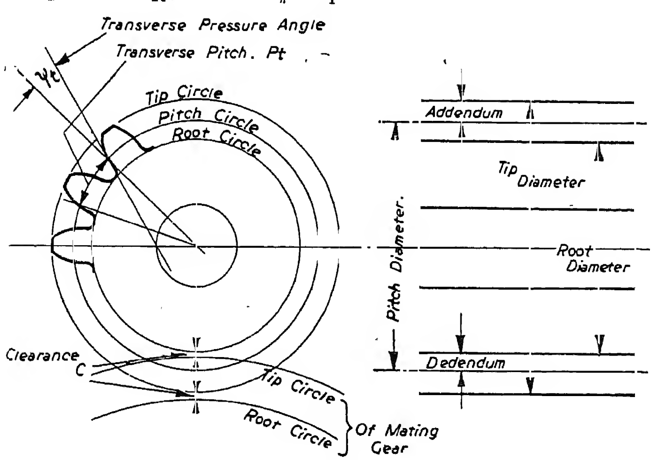


Fig. 1.—Symbols and terms relating to spur gears.

Facewidth should be between $3p$ and $6p$. It should not be less than $\frac{D}{15}$ or more than $2d$.

Helical Gears (see Fig. 2):

$C = \frac{1}{2}(d + D)$.

$p_t = \frac{2\pi C}{T + t}$.

$p_n = p_t \cos\sigma$.

$d = \frac{t p_t}{\pi} = \frac{t}{P_t}$.

$a = \frac{1}{P_n}\left(1{\cdot}4 - \frac{0{\cdot}4}{R}\right)$.

$b = \frac{1}{P_n}\left(0{\cdot}85 + \frac{0{\cdot}4}{R}\right)$.

$c = \frac{0{\cdot}25}{P_n}$.

$i = d - 2b$.

$j = d + 2a$.

$P_t = \frac{T + t}{2C}$.

$p_a = p_n \operatorname{cosec}\sigma = p_t \cot\sigma$

$D = \frac{T}{\pi} p_t = \frac{T}{P_t}$.

$A = \frac{1}{P_n}\left(0{\cdot}6 + \frac{0{\cdot}4}{R}\right)$.

$B = \frac{1}{P_n}\left(1{\cdot}65 - \frac{0{\cdot}4}{R}\right)$.

$I = D - 2B$.

$J = D + 2A$.

$L_p = \pi d \cot\sigma = p_t t \cot\sigma = p_n t \operatorname{cosec}\sigma$.

$L_w = \pi D \cot\sigma = p_t T \cot\sigma = p_n T \operatorname{cosec}\sigma$.

$\tan\psi_t = \tan\psi_n \sec\sigma$.

$\tan\psi_a = \tan\psi_n \operatorname{cosec}\sigma$.

End thrust $= \frac{2M}{d}\tan\sigma$.

Transverse force $= \frac{2M}{d}\sec\psi_t$.

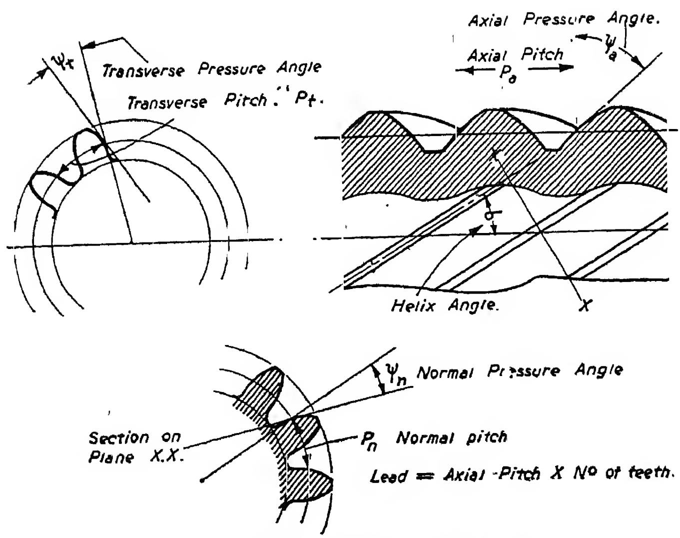


Fig. 2.—Symbols and terms relating to helical gears.

Facewidth should not be less than $\frac{D}{15}$ or more than $2d$ for single helical gears, or more than $2{\cdot}5d$ for double helicals.

Facewidth of one helix should not be less than $p_t \cot \sigma$.

Internal Gears (see Fig. 3).—The minimum permissible difference between the number of teeth in an internal gear and the number of teeth in a gear that meshes with it or in a pinion-type cutter that generates it is ten.

An internal gear rotates in the *same* direction as its mating gear.

The centre distance between an internal gear and its mating gear is half the *difference* between the pitch diameters.

The following formulæ apply to internal gears with helical teeth. The corresponding formulæ for straight teeth are derived from them by writing: $p_t \doteq p_n$ and $\sigma = 0$.

$$C = \tfrac{1}{2}(D - d).$$

$$p_t = \frac{2\pi C}{T - t}. \qquad P_t = \frac{T - t}{2C}.$$

$$p_n = p_t \cos \sigma. \qquad p_a = p_n \operatorname{cosec} \sigma = p_t \cot \sigma$$

$$d = \frac{tp_t}{\pi} = \frac{t}{P_t}. \qquad D = \frac{Tp_t}{\pi} = \frac{T}{P}.$$

$$a = \frac{1{\cdot}4}{P_n}. \qquad A = \frac{0{\cdot}6}{p_n}.$$

$$b = \frac{0{\cdot}85}{P_n}. \qquad B = \frac{1{\cdot}65}{p_n}.$$

$$c = \frac{0{\cdot}25}{P_n}.$$

$$i = d - 2b. \qquad I = D + 2B.$$

$$j = d + 2a. \qquad J = D - 2A.$$

$$L_p = \pi d \cot \sigma = p_t t \cot \sigma = p_n t \operatorname{cosec} \sigma.$$

$$L_w = \pi D \cot \sigma = p_t T \cot \sigma = p_n T \operatorname{cosec} \sigma.$$

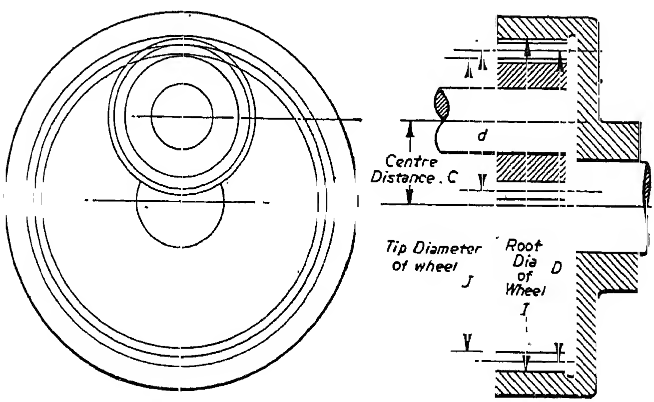


Fig. 3.—Symbols and terms relating to internal gears.

The desirable relations between diameter, pitch and facewidth laid down for external spur and helical gears also apply to the corresponding internal gears. The pinion has usually to be "overhung," and in that case the pinion-shaft diameter should not be less than the facewidth.

When generating gear teeth by means of a pinion-type cutter, the lead of the cutter must be equal to the lead of the helical guides in the generating machine and consequently:

$$\text{Lead of gear} = \text{Lead of guides} \times \frac{\text{Number of teeth in gear}}{\text{Number of teeth in cutter}}.$$

The helix angle σ of gear and cutter is determined by:

$$\tan \sigma = \pi \times \frac{\text{Pitch diameter of cutter}}{\text{Lead of guides}},$$

or by

$$\sin \sigma = \frac{\text{Number of teeth in cutter}}{\text{Lead of guides}} \times p_n.$$

Spiral Gears (see Fig. 4):

$$C = \tfrac{1}{2}(d + D).$$

$$p_n = \frac{2\pi C}{T \sec \sigma_w + t \sec \sigma_p}.$$

$$p_{tp} = p_n \sec \sigma_p. \qquad p_{tw} = p_n \sec \sigma_w.$$

$$\sigma_p + \sigma_w = \Sigma.$$

NOTE.—p_n is common to pinion and wheel, but transverse pitch (p_t) and axial pitch (p_a) are in general different for pinion and wheel.

$$d = \frac{t p_{tp}}{\pi} = \frac{t}{P_{tp}}.$$

$$R_2 = \frac{T}{t}\left(\frac{\cos \sigma_p}{\cos \sigma_w}\right)^3.$$

$$a = \frac{1}{P_n}\left(1{\cdot}4 - \frac{0{\cdot}4}{R_2}\right).$$

$$b = \frac{1}{P_n}\left(0{\cdot}85 + \frac{0{\cdot}4}{R_2}\right).$$

$$c = \frac{0{\cdot}25}{P_n}.$$

$$i = d - 2b.$$

$$j = d + 2a.$$

$$L_p = \pi d \cot \sigma_p$$
$$= p_t\, t \cot \sigma_p$$
$$= p_n\, t \operatorname{cosec} \sigma_p$$

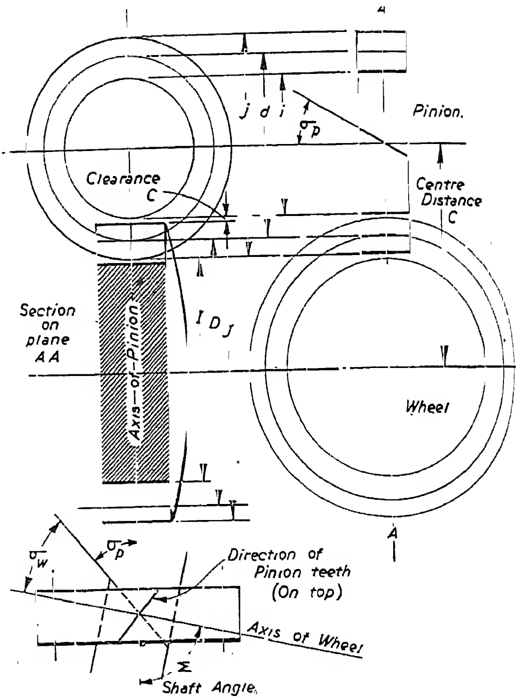


Fig. 4.—Symbols and terms relating to spiral gears.

$$D = \frac{Tp_{tw}}{\pi} = \frac{T}{P_{tw}}. \qquad B = \frac{1}{P_n}\left(1{\cdot}65 - \frac{0{\cdot}4}{R_2}\right).$$

$$A = \frac{1}{P_n}\left(0{\cdot}6 + \frac{0{\cdot}4}{R_2}\right). \qquad I = D - 2B.$$

$$J = D + 2A.$$

$L_w = \pi D \cot \sigma_w = p_t T \cot \sigma_w = p_n T \operatorname{cosec} \sigma_w.$

$\tan \psi_{tp} = \tan \psi_n \sec \sigma_p.$

$\tan \psi_{tw} = \tan \psi_n \sec \sigma_w.$

End thrust on pinion $= \dfrac{2M}{d} \tan \sigma_p.$

End thrust on wheel $= \dfrac{2T}{t}\dfrac{M}{D} \tan \sigma_w.$

Transverse force on pinion $= \dfrac{2M}{d} \sec \psi_{tp}.$

Transverse force on wheel $= \dfrac{2T}{t}\dfrac{M}{D} \sec \psi_{tw}.$

Facewidth of pinion should not be less than $3p_n \sin \sigma_p$ or than $\dfrac{d}{12}.$

Facewidth of wheel should not be less than $3p_n \sin \sigma_w$ or than $\dfrac{D}{12}.$

The determination of suitable numbers of teeth and helix angles for spiral gears involves repeated assumptions and trials because there are several variables. The following procedure is suggested as affording useful guidance:

(*a*) Select t from Table I and then $T = Rt$,

(*b*) Assume $\sigma_p = \sigma_w = \dfrac{\Sigma}{2}.$

(*c*) Then $p_n = \dfrac{2\pi C}{(T + t)\sec\frac{\Sigma}{2}}.$

Usually this will not be a standard pitch, and alternative values of t may be tried in order to find which will make p_n to be as close as possible to a standard pitch. Final adjustment is made by changing the helix angles.

(*d*) Assume σ_p to be, say, 10 degrees different from $\dfrac{\Sigma}{2}$, and of course $\sigma_w = \Sigma - \sigma_p.$

(*e*) Then $p_n = \dfrac{2\pi C}{T \sec \sigma_w + t \sec \sigma_p}.$

(*f*) Further values of σ_p must be tried until p_n is equal to a standard pitch.

When this has been successfully done, it is necessary to calculate the diameters of the gears to make sure that they are acceptable. If not, further trials must be made with different values of t and T.

It may be noted that for the case of perpendicular shafts ($\Sigma = 90°$), the maximum pitch for a given centre distance occurs when $\tan \sigma_p = \sqrt[3]{\dfrac{T}{t}}.$

Bevel Gears (see Fig. 5):

$\theta_p + \theta_w = \Sigma.$

$$\tan \theta_p = \frac{\sin \Sigma}{\cos \Sigma + \frac{T}{t}}.$$

$$\tan \theta_w = \frac{\sin \Sigma}{\cos \Sigma + \frac{t}{T}}.$$

For shafts at right angles, $\Sigma = 90°$, and these reduce to:

$\tan \theta_p = \frac{t}{T}$.

$\tan \theta_w = \frac{T}{t}$.

$d = 2C \sin \theta_p$. $\quad D = 2C \sin \theta_w$.

Note that pitch, addendum, dedendum, clearance, etc., are measured at the

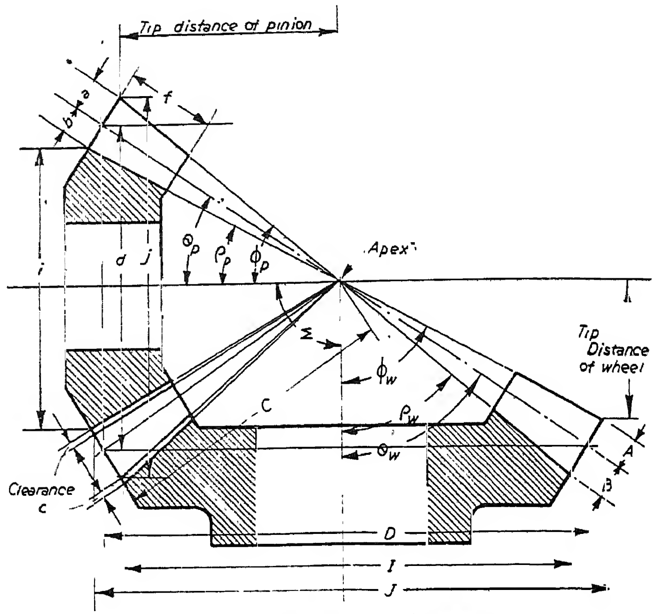


Fig. 5.—Symbols and terms relating to bevel gears.

large end of the tooth. If the gears are cut by a generating process it is not necessary to adhere to standard pitches.

$p = \frac{\pi d}{t} = \frac{\pi D}{T}$. $\quad P = \frac{t}{d} = \frac{T}{D}$.

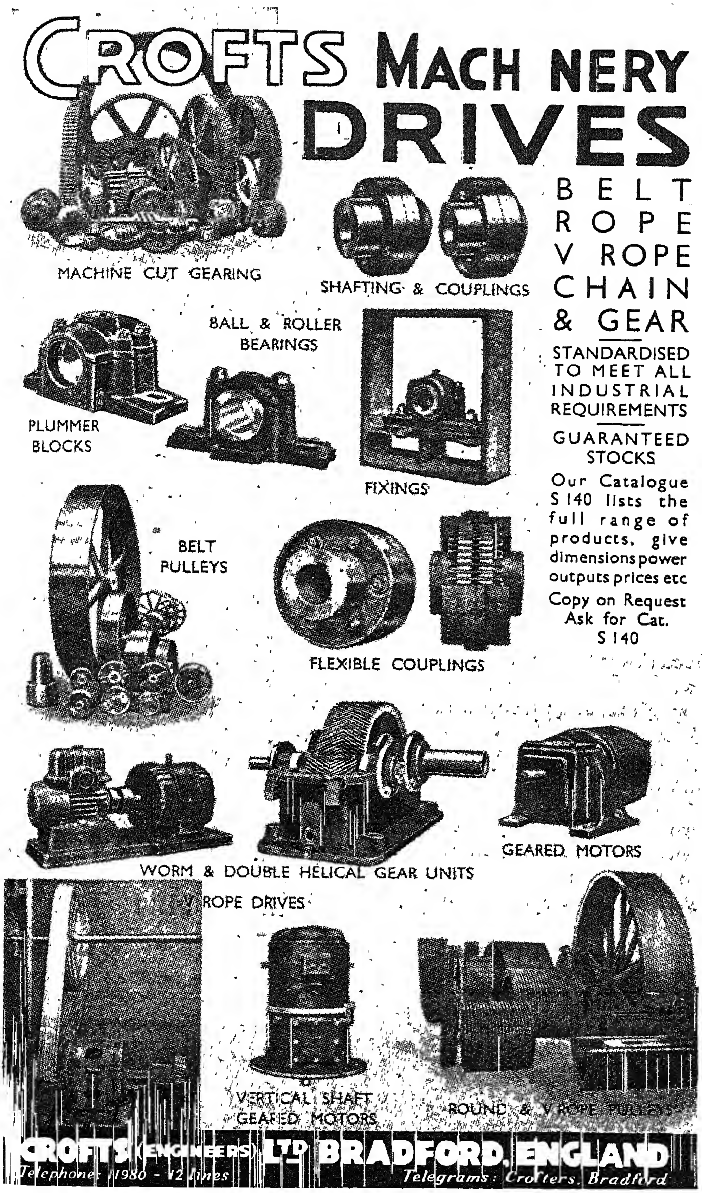
For shafts at right angles:

$C = \frac{1}{2}\sqrt{(d^2 + D^2)}$.

In general $C = \frac{d}{2} \operatorname{cosec} \theta_p$.

$R_1 = \frac{T}{t} \frac{\sec \theta_w}{\sec \theta_p}$.

$a = \frac{1}{P}\left(1{\cdot}4 - \frac{0{\cdot}4}{R_1}\right)$. $\quad A = \frac{1}{P}\left(0{\cdot}6 + \frac{0{\cdot}4}{R_1}\right)$.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V ROPE DRIVES
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GA

$b = \frac{1}{P}\left(0.85 + \frac{0.4}{R_1}\right).$ $B = \frac{1}{P}\left(1.65 - \frac{0.4}{R_1}\right).$

$c = \frac{0.25}{P}.$

$i = d - 2b \cos \theta_p.$ $I = D - 2B \cos \theta_w.$

$j = d + 2a \cos \theta_p.$ $J = D + 2A \cos \theta_w.$

$\phi_p = \theta_p + \left(3{,}440 \frac{a}{C}\right)$ minutes. $\phi_w = \theta_w + \left(3{,}440 \frac{A}{C}\right)$ minutes.

$\rho_p = \theta_p - \left(3{,}440 \frac{b}{C}\right)$ minutes. $\rho_w = \theta_w - \left(3{,}440 \frac{B}{C}\right)$ minutes.

Tip distance of pinion (see Fig. 5) $= \frac{d}{2} \cot \theta_p - a \sin \theta_p.$

Tip distance of wheel (see Fig. 5) $= \frac{D}{2} \cot \theta_w - A \sin \theta_w.$

End thrust on pinion $= \frac{2M}{d} \frac{\sin \theta_p}{1 - (f/2C)} \tan \psi_t.$

End thrust on wheel $= \frac{2M}{d} \frac{\sin \theta_w}{1 - (f/2C)} \tan \psi_t.$

Transverse force on pinion $= \frac{2M}{d} \frac{\sqrt{(1 + \tan^2 \psi_t \cos^2 \theta_p)}}{1 - (f/2C)}.$

Transverse force on wheel $= \frac{2M}{d} \frac{\sqrt{(1 + \tan^2 \psi_t \cos^2 \theta_w)}}{1 - (f/2C)}.$

Facewidth must not exceed $\frac{C}{3}.$

Facewidth should be between $\frac{3}{2}p$ and $3p.$

Wormgears (see Fig. 6).—The worm diameter d is usually determined from the centre distance C or the wheel diameter D. A satisfactory rule for general guidance *in the preliminary stages* is:

$d = \frac{C}{3}$ or $\frac{D}{5}$ and $D = 2C - d$ or $C = \frac{1}{2}(d + D).$

The number of threads in the worm may be determined from Table I.

Then $T = Rt$

and m is the nearest standard value (from Table II) to $\frac{D}{T}.$

On the British Standards system the dimensions of a pair of wormgears can all be determined from the "designation" which is $\frac{t}{T}/q/m.$ Here:

t = number of threads in worm.

m = module $= \frac{\text{axial pitch of worm}}{\pi}.$

$q = \frac{\text{diameter of worm}}{m}.$

T = number of teeth in wormwheel.

$q = \frac{d}{m}$, but it should preferably be a standard value (by quarters up to 4, by halves thence to 8, and above 8 by whole numbers). The value of d has usually to be adjusted so that q and m are standard quantities. Then $D = 2C - a$. provided that this lies between $m(T - 0.5)$ and $m(T + 0.5)$. If the centre distance C is not fixed, it is preferable to make $D = Tm$ and then $C = \frac{1}{2}(d + D).$

TABLE II

RECOMMENDED STANDARD VALUES OF m FOR WORMGEARS

Up to 0·5	In steps of 0·01
0·5 to 0·8	In steps of 0·02
Over 0·8	In steps of 0·05

Formulæ

$d = qm$. D = any value between $m(T - 0{\cdot}5)$ and $m(T + 0{\cdot}5)$.

$\tan \lambda = \frac{t}{q}$.

$a = m$. $i = d - 2b$. $f_w = 2m\sqrt{(q + 1)}$.

$b = m(2{\cdot}2 \cos \lambda - 1)$. $j = d + 2a$. $I = D - 2B$.

$c = 0{\cdot}2m \cos \lambda$. $A = m(2 \cos \lambda - 1)$. $J = D + 2A + m$.

$f_p = 10m$. $B = m(1 + 0{\cdot}2 \cos \lambda)$. $G = D + 2A$.

Suffix $_p$ refers to the worm ; $_w$ refers to the wormwheel.

$L_p = \pi tm$.

$\tan \psi_{ap} = \tan \psi_n \sec \lambda$. $\tan \psi_{aw} = \tan \psi_n \operatorname{cosec} \lambda$.

$\tan \psi_{tp} = \tan \psi_n \operatorname{cosec} \lambda$. $\tan \psi_{tw} = \tan \psi_n \sec \lambda$.

End thrust on worm $= \frac{2\pi M}{L_p} = \frac{2M}{tm}$.

End thrust on wormwheel $= \frac{2M}{d}$.

Transverse force on worm $= \frac{2M}{d} \sec \psi_{tp}$.

Transverse force on wormwheel $= 2\frac{T}{t}\frac{M}{D} \sec \psi_{tw}$.

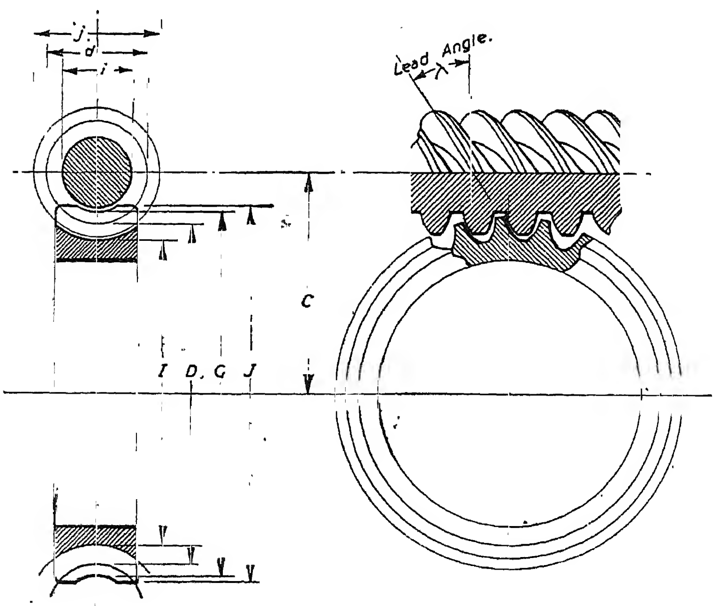


Fig. 6.—Symbols relating to wormgears.

Allowable Loading of Gears.—(*a*) *Spur, Helical and Bevel Gears :* Assuming the number of teeth in the pinion to be approximately that specified in Table I, the allowable torque on the pinion is given by :

$$M_0 = \frac{f\,d^{1\cdot8}\,K\,Z\,V}{\sqrt[5]{n}}\left(360 - \frac{240}{\sqrt{R_1}}\right)\sqrt[3]{\left(\frac{27{,}000}{1{,}000 + Y}\right)}\ \text{lb.-in.}$$

where f = facewidth.

d = pitch diameter of pinion, except for bevel gears when it is replaced by $d\left(1 - \frac{f}{2C}\right)$

K = angle factor (Table III).

Z = material factor (Table IV).

n = speed of pinion (r.p.m.) or 1, whichever is the greater.

R_1 = $T \sec \theta_w / t \sec \theta_p$ [equal to T/t for spur or helical gears].

V = $(\sec \theta_p)^{0\cdot8}$ [unity for spur and helical gears].

Y = desired running life (hours).

This is an approximate formula that agrees in a general way with B.S.S. 436 and 545.

Small departures (up to 15 per cent.) from the numbers of teeth specified in Table I make little difference to load capacity.

Material combinations should preferably be selected from those given in Table IV. For steels (not case-hardened) the value of Z is roughly proportional to the square of the tensile strength of the weaker member.

TABLE III

VALUES OF K

	$\psi_n = 20°$	$\psi_n = 14\frac{1}{2}°$
0	0·75	0·65
20°	0·85	0·74
30°	1·00	0·87
45°	1·50	1·30

TABLE IV

VALUES OF Z

Materials	Z
Pinion : En.8. 0·4 per cent. carbon steel, 40 tons tensile .. Wheel : Cast iron	0·65
Pinion : En.11. 0·55 per cent. carbon steel, 50 tons tensile .. Wheel : En.8. 0·4 per cent. carbon steel, 40 tons tensile ..	0·95
Pinion : En.27. Nickel-chrome steel, 60 tons tensile .. .. Wheel : En.11. 0·55 per cent. carbon steel, 50 tons tensile ..	1·35
Pinion : En.30. Nickel-chrome steel, 85 tons tensile .. .. Wheel : En.27. Nickel-chrome steel, 60 tons tensile	2·0
Pinion / Wheel En.34. Nickel-molybdenum case-hardened steel ..	4·7

(*b*) *Wormgears:* Assuming the dimensions of the gears to be in accordance with the formulæ already given, the allowable torque on the *wormwheel* is determined approximately by:

$$U = \frac{48\,D^{2\cdot8}}{\sqrt[3]{N}} \left(0{\cdot}4 + \frac{1{\cdot}35}{\sqrt{R}}\right) \sqrt[3]{\left(\frac{27{,}000}{1{,}000 + Y}\right)}$$

where D = diameter of wormwheel.
N = speed of wormwheel (r.p.m.) or 10, whichever is the greater.
R = T/t.
Y = desired running life (hours).

This is an approximate formula that agrees in a general way with B.S.S. 721.

The facewidth of the wormwheel is assumed to be $2m\sqrt{(q+1)}$, which is the maximum permissible. If it is less than this, the allowable torque is reduced proportionately.

The formula is applicable for wormwheel speeds up to about 200 r.p.m.

The materials are assumed to be case-hardened steel for the worm and phosphor bronze for the wormwheel. The worm may be made from a plain carbon steel or from nickel-chrome steel; in such cases the allowable load derived from the above formula is to be multiplied by:

$$\frac{\text{Tensile strength of worm (tons per sq. in.)}}{100}.$$

In any case, the worm threads must be highly polished; precision grinding is essential for rubbing speeds higher than 500 f.p.m.

Rubbing speed = $0{\cdot}262\,nm\sqrt{(t^2 + q^2)}$ f.p.m.

Efficiency of Gears.—The efficiency of a gear assembly depends on tooth friction, bearing friction, and oil-drag loss, the latter being very considerable in high-speed gears lubricated by oil bath.

In spur, helical, and bevel gears, the tooth loss is from ½ to 1 per cent. of the transmitted power. The bearing loss is about 1 per cent. of the transmitted power in the case of ball or roller bearings; for sleeve bearings the loss is about 1 per cent. of the power *transmitted at full load*, even when the gears are operating at less than full load.

The oil-drag loss at all loads is about 1 per cent. of the *power transmitted at full load*.

It will be seen from this that the full-load efficiency is from 97 to 97½ per cent., but the efficiency at fractional loads is lower.

In the case of wormgears and spiral gears the accurate calculation of efficiency is difficult, but a useful rule is that the full-load efficiency is $\left(100 - \frac{\text{reduction ratio}}{2}\right)$ per cent. falling to (100 − reduction ratio) per cent. at half load.

Calculating Change Gears.—In many gear-cutting machines, as in screw-cutting lathes, assemblies of "change gears" are used to secure a desired ratio between the speeds of two shafts. In the case of a screw-cutting lathe, the velocity ratio of the gear train is determined by the relation:

$$\frac{\text{Product of numbers of teeth in driving gears}}{\text{Product of numbers of teeth in driven gears}} = \frac{\text{Lead of screw to be cut}}{\text{Lead of lathe guide screw}}$$

In the case of a milling machine set up to cut a helical groove the relation is:

$$\frac{\text{Product of numbers of teeth in driving gears}}{\text{Product of numbers of teeth in driven gears}} = \frac{\text{Lead of helix to be cut}}{\text{Lead of table feed screw}} \times \frac{1}{N}$$

where N is the number of revolutions of the first driving gear per revolution of the work. This is usually 40.

The "formula" for the ratio of the change gears in any assembly should be provided by the maker of the machine.

The problem of determining suitable numbers of teeth in the change gears to give the required ratio is conveniently handled by the method of continued fractions.

Suppose, for example, that the fraction in a particular case is equal to 0·3286.

This is written as $\frac{3,286}{10,000}$, and the first step is to divide 10,000 by 3,286 and then to divide the remainder into 3,286. This procedure is repeated until there is no remainder; it is illustrated by its application (shown below) to the case under consideration:

23	3,286	10,000	3
	3,266	9,858	
10	20	142	7
	20	140	
	0	2	

First 3,286 is divided into 10,000, giving quotient 3 and remainder 142. This is divided into 3,286, giving quotient 23 and remainder 20. This is divided into 142, giving quotient 7 and remainder 2. This is divided into 20, giving quotient 10 and remainder 0. The successive quotients are thus 3, 23, 7, 10. From these is built up a series of fractions, of which the first is $\frac{1}{3}$ and the second is $\frac{23 \times 1 + 0}{23 \times 3 + 1} = \frac{23}{70}$. The added quantities 0 and 1 are the same for all problems. The third fraction is determined from the first and the second with the aid of the third quotient (7), thus:

$$\frac{7 \times 23 + 1}{7 \times 70 + 3} = \frac{162}{493}.$$

The last fraction is, similarly, $\frac{10 \times 162 + 23}{10 \times 493 + 70} = \frac{1,643}{5,000}$.

As this is equal to the original fraction $\frac{3,286}{10,000}$, the accuracy of the working is proved.

The succession of fractions is $\frac{1}{3}\ \frac{23}{70}\ \frac{162}{493}\ \frac{1,643}{5,000}$ and the aim is to determine a combination of gear tooth numbers that gives a value equal to a fraction as close as possible to the right-hand end of the list:

Thus $\frac{30}{90} = \frac{1}{3} = 0{\cdot}333$ instead of $0{\cdot}3286$.

Again, $\frac{23}{70} = 0{\cdot}32857$, which is sufficiently accurate for most requirements.

The next fraction $\frac{162}{493} = \frac{2 \times 81}{9 \times 17} = \frac{20 \times 81}{90 \times 17}$, and these numbers of teeth are reasonable. The value of the fraction $\frac{162}{493}$ is $0{\cdot}3286004$, and this is very nearly correct.

If this solution had not been acceptable for any reason, the last fraction might be considered, thus:

$$\frac{1,643}{5,000} = \frac{31 \times 53}{50 \times 100}, \text{ and this is exact.}$$

Other approximating fractions may be determined by adding numerator and denominator of any of the four fractions to any multiple of the numerator and denominator of the adjacent fractions, e.g.:

$$\frac{23 + 2 \times 162}{70 + 2 \times 493} = \frac{347}{1,056}$$

or

$$\frac{23 + 5 \times 162}{70 + 5 \times 493} = \frac{833}{2,535}$$

In any particular case a large number of approximating fractions can easily be determined in this way, but any particular one is useful only if:

(*a*) it can be factorised into suitable tooth numbers, and
(*b*) it is sufficiently accurate.

There are methods of determining what is the most accurate combination possible within a certain maximum number of teeth in the gears, but they are a little difficult to understand unless special study is given to the subject, and the method described above, although leaving something to the judgment of the calculator, is adequate for most normal purposes.

As a further example, for the case of a fraction greater than 1, the figure 2·317 may be considered. This is cleared of decimals by writing it $\frac{2,317}{1,000}$, and the procedure is generally the same as before. The first step, however, must be different, because 2,317 cannot be divided into 1,000; instead 1,000 is divided into 2,317, and the calculation proceeds thus:

2	2,317	1,000	3
	2,000	951	
6	317	49	2
	294	46	
7	23	3	1
	21	2	
2	2	1	
	2		
	0		

The successive quotients are 2, 3, 6, 2, 7, 1, 2. The first fraction is $\frac{2}{1}$ and, as this is greater than unity, the next step, using the second quotient (3) is *not* $\frac{3 \times 2 + 0}{3 \times 1 + 1}$ as in the previous example, but $\frac{3 \times 2 + 1}{3 \times 1 + 0} = \frac{7}{3}$.

Then for the next fraction, using the third quotient (6), $\frac{6 \times 7 + 2}{6 \times 3 + 1} = \frac{44}{19}$ and so on. The complete series is:

$$\frac{2}{1} \quad \frac{7}{3} \quad \frac{44}{19} \quad \frac{95}{41} \quad \frac{709}{306} \quad \frac{804}{347} \quad \frac{2,317}{1,000}.$$

Of these $\frac{95}{41}$ may be used (with an idler gear), but the other numbers have no convenient factors.

The value of $\frac{95}{41}$ is 2·31707, and thus is sufficiently accurate for most purposes. Alternatives are obtained by subtracting multiples of 95 and 41 from 709 and 306 until suitable fractions are found.

Thus $\frac{709 - 95}{306 - 41} = \frac{614}{265} = \frac{2 \times 307}{5 \times 53}$, but 307 has no factors;

$\frac{709 - 2 \times 95}{306 - 2 \times 41} = \frac{519}{224} = \frac{3 \times 173}{4 \times 56}$, but 173 has no factors;

$\frac{709 - 3 \times 95}{306 - 3 \times 41} = \frac{424}{183} = \frac{8 \times 53}{3 \times 61}$;

which admits of change gears $\frac{80 \times 53}{30 \times 61}$.

The value of this last fraction lies between $\frac{95}{41}$ and $\frac{709}{306}$ and is more accurate than the former (2·31707).

Epicyclic Gears.—The difficulty of understanding the operation of epicyclic gears arises from the fact that the centre-lines of one or more gears in the assembly are not fixed. The general method of dealing with the subject is to assume that the centres *are* fixed and that all the gears are free to rotate, and to work out the algebraic relations between the relative rotations of the gears on that basis. It is then a matter of simple arithmetic to find out what happens to the various gears and shafts when certain gears are fixed and the centre-lines of other gears are allowed to move.

The principle is illustrated by the simplest type of epicyclic gear (Fig. 7), in which a pinion A meshes with a gear B rotatably mounted on a pin projecting from an arm C that rotates about the centre-line of A. The gear B meshes with a stationary internal gear D. It is desired to determine the rotation of each element of the assembly when A rotates through one revolution.

The procedure in analysing this assembly is first of all to assume that the centre-lines of all gears are fixed. This means that the centre-line of B must be

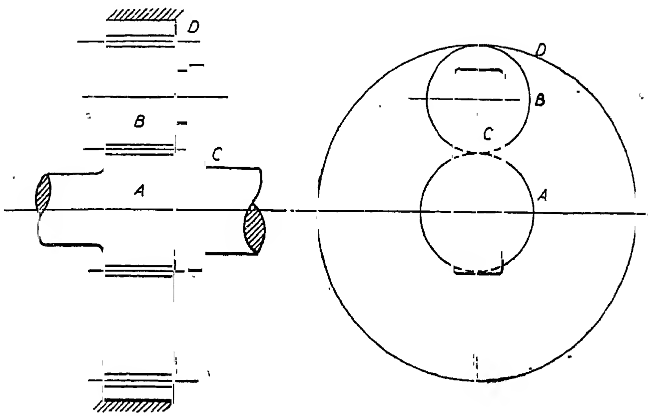


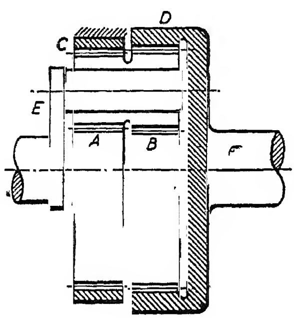
Fig. 7.—Epicyclic gears.

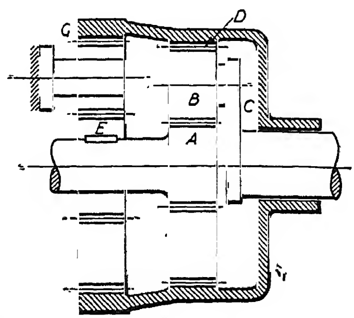
fixed, and therefore that C must not be allowed to rotate. To admit of any movement at all, the internal gear D must be allowed to rotate. If A is rotated through one revolution, the corresponding rotations of B and D are determined in the ordinary manner. If the letters A, B, and D are used to represent the numbers of teeth in the corresponding gears, then for one revolution of A the gear B turns through $-\frac{A}{B}$ revolutions. The minus sign is used because B turns in the opposite direction to A. The gear D turns through $\left(-\frac{A}{B}\right) \times \frac{B}{D} = -\frac{A}{D}$ revolutions.

Because D is an internal gear, it rotates in the same direction as B, and therefore the number of revolutions of B is multiplied by $\frac{B}{D}$ and not $-\frac{B}{D}$ as would be the case if B and D were external gears. The minus signs are of great importance and must not on any account be omitted. The rotations are recorded in Line 1 of Table V.

TABLE V

	A	B	C	D
Line 1	1	$-\frac{A}{B}$	0	$-\frac{A}{D}$
Line 2	$1+\frac{A}{D}$	$-\frac{A}{B}+\frac{A}{D}$	$\frac{A}{D}$	0
Line 3	1	$\frac{-\frac{A}{B}+\frac{A}{D}}{1+\frac{A}{D}}$	$\frac{\frac{A}{D}}{1+\frac{A}{D}}$	0





Figs. 8 (*Right*) and 9.—Another arrangement of internal gears.

In such a table as this a line may be developed from a preceding one by:

(*a*) increasing or reducing every quantity in it by the same amount; or

(*b*) multiplying or dividing every quantity in it by the same amount.

In analysing epicyclic gear trains in general, advantage is taken of these possibilities to produce the desired quantity in a certain column. In this particular instance it is known that the internal gear D is stationary, and so the quantity in the fourth column must be zero. This result can be achieved by adding $\frac{A}{D}$ to each of the quantities in Line 1. In this way Line 2 is developed and the quantities in that line represent the rotations of the corresponding members.

If it is desired to know what rotations will occur when A rotates through one revolution whilst D still has zero revolutions, it is necessary to *divide* throughout by $1+\frac{A}{D}$, because this will produce unity in the first column and will leave zero unaltered in the last column as is required. In this way Line 3 is obtained.

For one revolution of A the number of revolutions of B is:

$$\frac{-\frac{A}{B}+\frac{A}{D}}{1+\frac{A}{D}}=\frac{A}{B}\left(\frac{B-D}{D+A}\right)$$

and the number of revolutions of C is:

$$\frac{\frac{A}{D}}{1+\frac{A}{D}} = \frac{A}{D+A}.$$

It should be observed that the number of revolutions of B *around its spindle* is different from the quantity mentioned above, because the spindle is fixed to C and therefore has the same number of revolutions as C. The number of revolutions of B around its spindle is the difference of these quantities:

$$\text{i.e. } \frac{A}{B}\left(\frac{B-D}{D+A}\right) - \frac{A}{D+A} = -\frac{AD}{B\,(D+A)}.$$

Another Arrangement.—In Fig. 8 the arrangement of Fig. 7 is repeated with the addition of gearing that causes D, instead of being stationary, to rotate at $-\frac{E}{G}$ times the speed of A. One way of determining the ratios for this arrangement is to consider in the first instance only the ABCD assembly, giving Line 1 of Table VI. Then, since the ratio of D's revolutions to those of A is known to be $-\frac{E}{G}$, it is required to know what quantity must be added to $-\frac{A}{D}$ and to 1 in order to produce quantities having that ratio. Let the added quantity be k.

This is added to all the quantities in Line 1, producing Line 2.

$$\text{Then } \frac{-\frac{A}{D}+k}{1+k} = -\frac{E}{G}$$

$$\text{from which } k = \frac{\frac{A}{D}-\frac{E}{G}}{1+\frac{E}{G}}.$$

TABLE VI

	A	B	C	D
Line 1 ..	1	$-\frac{A}{B}$	0	$-\frac{A}{D}$
Line 2 ..	$1+k$	$-\frac{A}{B}+k$	k	$-\frac{A}{D}+k$
Line 3 ..	1	$\frac{-\frac{A}{B}+k}{1+k}$	$\frac{k}{1+k}$	$\frac{-\frac{A}{D}+k}{1+k}$

In order to determine the revolutions made for one revolution of A, each quantity in Line 2 is divided by $1+k$, giving Line 3.

The number of revolutions of C for one revolution of A is thus:

$$\frac{k}{1+k} = \frac{\frac{A}{D}-\frac{E}{G}}{1+\frac{E}{G}} \cdot \frac{1}{1+\frac{\frac{A}{D}-\frac{E}{G}}{1+\frac{E}{G}}} = \frac{\frac{A}{D}-\frac{E}{G}}{1+\frac{A}{D}} = \frac{A-\frac{DE}{G}}{D+A}$$

Compound Epicyclic Gear.—The compound epicyclic gear shown in Fig. 9 may be analysed by the same general method. Gears A and B are rigidly fixed

together, and their numbers of revolutions are therefore always identical. The internal gear C is fixed and D is the driven gear.

In the first instance it is assumed that the arm E is stationary and that both internal gears are free to rotate. Line 1 (Table VII) corresponds to this condition, A having one revolution. To represent the actual conditions, C must have zero revolutions, and to secure this, the quantity $\frac{A}{C}$ is added to each quantity in Line 1, giving Line 2. Division throughout by $\frac{A}{C}$ gives Line 3, from which it will be seen that for one revolution of E the internal gear D makes:

$$\frac{-\frac{B}{D}+\frac{A}{C}}{\frac{A}{C}} = \frac{-BC+AD}{AD} \text{ revolutions.}$$

TABLE VII

	A, B	C	D	E
Line 1 ..	1	$-\frac{A}{C}$	$-\frac{B}{D}$	0
Line 2 ..	$1+\frac{A}{C}$	0	$-\frac{B}{D}+\frac{A}{C}$	$\frac{A}{C}$
Line 3 ..	$\frac{1+\frac{A}{C}}{\frac{A}{C}}$	0	$\frac{-\frac{B}{D}+\frac{A}{C}}{\frac{A}{C}}$	1

By suitable choice of the numbers of teeth A, B, C, and D, the quantity BC may be made nearly equal to DA, and the rotation of D is then extremely small. In other words, the ratio of reduction of speed in the assembly is very high.

It must be noted, however, that the efficiency of a high-ratio epicyclic gear of this type is very low, and consequently it is suitable only for low powers.

GEAR-CUTTING

The information given here is primarily intended to apply to gears cut by generating processes. In the case of spur, helical, and spiral gears, the more commonly used generating processes are those using hobs, rack-shaped cutters (Sunderland), and pinion-shaped cutters (Fellows, Sykes). The recommended tooth form is the British Standard (with normal pressure angle of 20 degrees) and with a generating cutter made in accordance with that standard, the information required for making the blanks and setting up the gear-cutting machine includes outside diameters, numbers of teeth, normal pitch or transverse pitch, helix angle and lead. The teeth are cut to a specified thickness on a specified circle, and the action of the machine automatically produces the correct tooth shape. Similar remarks apply in the case of bevel gears.

In manufacturing wormgears it is necessary to make the dimensions of the worm correspond to those of the hob used for generating the wormwheel teeth. Wormgears should preferably be designed so that an existing hob can be used.

It may be desired to cut spur, helical, or spiral gears on a universal milling machine. This may be done by using rotary formed cutters of the Brown and Sharpe type, but the accuracy of the gears will not approach that of gears generated on high-class gear-cutting machines, and so quiet running at high speeds must not be expected. When cutting a gear having t teeth, normal pitch p_n and helix

TABLE VIII.—STANDARD PITCHES OF GEARS

Circular Pitch (in.)	D.P. (in.)	Module (mm.)	Circular Pitch (in.)	D.P. (in.)	Module (mm.)	Circular Pitch (in.)	D.P. (in.)	Module (mm.)
0·1855	16·933	**1·5**	0·618	5·080	**5**	1·396	**2·25**	11·286
0·1875	16·755	1·516	**0·625**	5·026	5·053	1·484	2·117	**12**
0·1963	**16**	1·587	0·628	**5**	5·077	**1·5**	2·094	12·127
0·2164	14·514	**1·75**	0·680	4·618	**5·5**	1·571	**2**	12·701
0·2244	**14**	1·814	**0·6875**	4·569	5·558	1·608	1·954	**13**
0·247	12·700	**2**	0·742	4·233	**6**	**1·625**	1·933	13·138
0·250	12·566	2·021	**0·75**	4·189	6·064	1·732	1·814	**14**
0·262	**12**	2·118	0·7854	**4**	6·350	**1·75**	1·795	14·148
0·278	11·288	**2·25**	**0·8125**	3·867	6·569	1·795	**1·75**	14·512
0·309	10·160	**2·5**	0·866	3·628	**7**	1·855	1·693	**15**
0·3125	10·053	2·527	**0·875**	3·590	7·074	**1·875**	1·676	15·159
0·314	**10**	2·540	0·898	**3·5**	7·260	1·978	1·587	**16**
0·340	9·236	**2·75**	**0·9375**	3·351	7·580	**2**	1·571	16·170
0·371	8·466	**3**	0·990	3·175	**8**	2·094	**1·5**	16·930
0·375	8·377	3·032	**1·000**	3·142	8·085	2·226	1·412	**18**
0·393	**8**	3·177	1·047	**3**	8·465	**2·25**	1·396	18·191
0·433	7·257	**3·5**	1·113	2·822	**9**	2·474	1·270	**20**
0·4375	7·181	3·537	**1·125**	2·792	9·095	**2·5**	1·257	20·212
0·449	**7**	3·630	1·142	**2·75**	9·233	2·513	**1·25**	20·317
0·495	6·350	**4**	1·237	2·54	**10**	**2·75**	1·142	22·233
0·5	6·283	4·042	**1·25**	2·513	10·106	**3**	1·047	24·254
0·524	**6**	4·236	1·257	**2·5**	10·163	3·142	**1**	25·400
0·557	5·644	**4·5**	1·361	2·309	**11**			
0 5625	5·585	4·547	**1·375**	2·285	11·117			

angle σ, the Brown and Sharpe cutter used must be the one appropriate for a spur gear of pitch p_n and having a number of teeth equal to $t \sec^3 \sigma$.

If it is necessary to cut quantities of spur or helical gears on the milling machine, it is preferable to use cutters specially made for the particular job. If a pair of correctly generated master gears can be obtained, they may be used as gauges with which to check the accuracy of the form of the milling cutters.

Contact Marking on Gear Teeth.—The contact between a pair of gears should always be tested when they are mounted in their correct relative positions for working together. The teeth of the pinion are lightly smeared with red lead or Prussian blue, and the gears rotated together under light resistance so as to exert some pressure on the teeth.

The marking thus made on the wheel teeth ought to spread across at least 60 per cent. of the facewidth, and should extend over the greater part of the working depth of the teeth but should not show heavily at the tips of the teeth. The contact on the pinion teeth is judged by the removal of the original marking substance, but it is preferable to clean the pinion teeth and to apply the marking substance to the wheel teeth, whence it is transferred to the pinion teeth by running the gears together.

The contact marking shown on bevel gear teeth by this procedure should be heavier towards the small ends of the teeth than elsewhere, because the effect of distortion of the mounting under load is to cause the contact area to move towards the large ends of the teeth. Change in position of contact area can be effected by axial adjustment of the gears relatively to the apex, and bearing mountings should be designed to facilitate such adjustment. No attempt should be made to alter the backlash by axial adjustment of the gears.

The light load contact marking on wormwheel teeth should be in the half of the facewidth away from the side at which the worm threads enter the spaces between the wormwheel teeth. The effect of distortion of mounting under load is to cause the contact area to move towards the entering side, but it should not be allowed to extend quite to it or lubrication troubles are likely. Lateral change in position of contact area can be effected by axial adjustment of the position of the wormwheel relatively to the worm. The "entering" edges of the wormwheel teeth should be chamfered by filing at 45 degrees to a width of about 0·05 in.

Readers are referred to *Gears and Gear Cutting*, by Camm.

B. & S. INVOLUTE GEAR CUTTERS

No. 1	will cut wheels from	135 teeth	to a	rack		inclusive.
,, 2	,, ,, ,, ,,	55	,, ,,	134	teeth	,,
,, 3	,, ,, ,, ,,	35	,, ,,	54	,,	,,
,, 4	,, ,, ,, ,,	26	,, ,,	34	,,	,,
,, 5	,, ,, ,, ,,	21	,, ,,	25	,,	,,
,, 6	,, ,, ,, ,,	17	,, ,,	20	,,	,,
,, 7	,, ,, ,, ,,	14	,, ,,	16	,,	,,
,, 8	,, ,, ,, ,,	12	,, ,,	13	,,	,,

CUTTERS FOR MITRE AND BEVEL GEARS

Diametral Pitch	*Diameter of Cutter*	*Hole in Cutter*	*Diametral Pitch*	*Diameter of Cutter*	*Hole in Cutter*
	in.	*in.*		*in.*	*in.*
4	$3\frac{1}{2}$	$1\frac{1}{4}$	12	3	$\frac{7}{8}$
5	$3\frac{1}{2}$	$1\frac{1}{4}$	14	3	$\frac{7}{8}$
6	$3\frac{1}{2}$	$1\frac{1}{4}$	16	$2\frac{3}{4}$	$\frac{7}{8}$
7	$3\frac{1}{2}$	$1\frac{1}{4}$	20	$2\frac{1}{2}$	$\frac{7}{8}$
8	$3\frac{1}{4}$	$1\frac{1}{4}$	24	$2\frac{1}{4}$	$\frac{7}{8}$
10	$3\frac{1}{4}$	$\frac{7}{8}$			

CHAIN WHEELS

Chain or sprocket wheels are gears made to mesh with chains, by means of which motion may be transmitted from one point to another. The teeth are of different formation from the ordinary involute gear, as they have to accommodate the circular rollers of the chain. Ordinary gearing calculations for pitch-line functions do not apply, for whereas with two gears in mesh with one another the circular pitch is the distance between two tooth centres measured round the pitch line, with a sprocket the circular pitch refers really to the chordal distance between two tooth centres. As information relating to these calculations is extremely scanty, the following formulæ for block-centre and roller-chain may be of interest.

Chain Wheels for Block-centre Chains.—Fig. 4 shows a wheel as used for block-centre chains, and the following formulæ give proportions and diameters relevant to them :

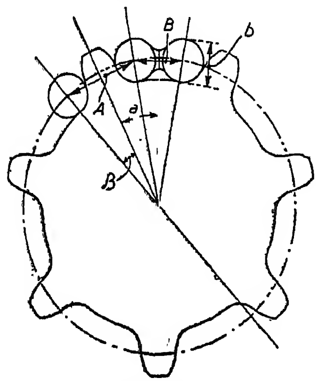


Fig. 1.—Sprocket proportion for block-centre chains.

$$= \frac{180^\circ}{N}. \qquad \text{Tan} = \frac{\sin a}{\frac{B}{A} + \cos a}$$

$$\text{Pitch diameter} = \frac{A}{\sin}$$

Outside diameter = pitch diameter + b. Bottom diameter = pitch diameter $-b$. In calculating the diameter of sprocket wheels the bottom diameter is most important. In the above calculations N = number of teeth, b = diameter of round part of chain block, B = centre to centre of holes in chain block, A = centre to centre of holes in side-links.

British Standard Roller Chain Wheels

$$\text{Pitch diameter} = \text{Chain pitch} \times \text{cosec}\left(\frac{180^\circ}{\text{No. of teeth}}\right).$$

Bottom diameter = Pitch diameter minus roller diameter.

Chordal distance = [$\frac{1}{2}$ (pitch diameter of wheel having twice the number of teeth) minus roller diameter].

Measurement over Pins.—The bottom diameter of wheels with *even* numbers of teeth is checked by measuring over pins inserted in opposite tooth spaces.

The bottom diameter of wheels with *odd* numbers of teeth is checked from chordal distance by measuring over pins inserted in the tooth spaces most nearly opposite.

Measurement over pins.
- For *even* numbers of teeth = pitch diameter plus roller diameter.
- For *odd* numbers of teeth = [$\frac{1}{2}$ (pitch diameter of wheel having twice the number of teeth) plus roller diameter].

Tolerance on Cutting Sizes.—*Bottom Diameter and Measurement over Pins*

Plus 0·000 in.

Minus 0·004 in. per in. (mm. per mm.) of pitch diameter, with a maximum of 0·020 in. (0·51 mm.), subject to the provision that a tolerance up to 0·005 in. (0·13 mm.) shall be permitted on all chain wheels with pitch diameter less than 5 in. (127·00 mm.).

Formula for Centre Distances

(Two-point Drives)

N = Number of teeth in wheel.
n = Number of teeth in sprocket.
D = Distance between centres.
L = Number of links in chain.
P = Pitch.

$$L = \frac{2 \times D}{P} + \frac{N + n}{2} + \frac{P \times (N - n)^2}{40D} \quad \text{(approx.).}$$

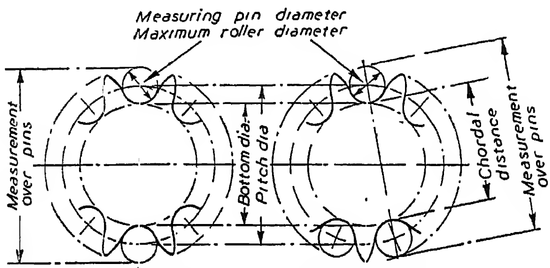


Fig. 2.—British Standard Roller Chain Sprocket proportions.

The result obtained from this expression will not ordinarily be a whole number of links; in that event the nearest even number should be taken and a recalculation made to find the corresponding centre distance from the following:

$$D = \frac{P}{8}\left[A + \sqrt{(A + 0{\cdot}9B) \times (A - 0{\cdot}9B)}\right]$$

where A = 2L − (N + n) and B = (N − n).

This formula gives results correct to within 0·05 per cent. for wheels having a ratio of 2 : 1 at minimum centres. This is sufficiently accurate for drives where adjustment is provided.

ROLLER CHAINS

Circular Pitch	*Dia. of Rolls*	*Dia. of Cutter*	*Hole in Cutter*
in.	*in.*	*in.*	*in.*
$\frac{1}{2}$	·306 or ·308	$2\frac{7}{8}$	1
$\frac{5}{8}$	·401	3	1
$\frac{3}{4}$	*·47	$3\frac{1}{4}$	1
$\frac{15}{16}$	·5625	$3\frac{3}{8}$	1
1	·5625 or *·625	$3\frac{1}{2}$	1
$1\frac{1}{4}$	·625 or *·750	$3\frac{3}{4}$	$1\frac{1}{4}$
$1\frac{1}{2}$	·75 or *·875	$4\frac{1}{2}$	$1\frac{1}{4}$
$1\frac{3}{4}$	*1	$4\frac{3}{4}$	$1\frac{1}{4}$
2	*1·125	5	$1\frac{1}{4}$

* "Whitney Standard."

BLOCK-CENTRE CHAINS

Circular Pitch	*Thickness of Block*	*Dia. of Cutter*	*Centre to Centre of Block*	*Hole in Cutter*
in.	*in.*	*in.*	*in.*	*in.*
$1\frac{5}{16}$	·4375	$3\frac{1}{2}$	·5313	$1\frac{1}{4}$
$1\frac{1}{2}$	$\frac{17}{32}$	$3\frac{3}{4}$	·5625	$1\frac{1}{4}$

Seven cutters are made for each pitch, for numbers of teeth as follows: 8, 9, 10, 11, 12, and 13, 14 to 16, 17 to 20, 21 and over.

BALL AND ROLLER BEARINGS

Types

There are a number of different types and designs of ball and roller bearings, known collectively as anti-friction bearings; but basically these all consist of the rolling elements, the race rings on which are provided tracks for the rolling elements, and in the majority of cases a separator for the rolling elements known as the cage.

The rolling elements may consist of balls, parallel rollers having considerable variation in the ratio length/diameter, taper rollers, or barrel-shaped rollers. Rollers generally have flat and parallel ends, but some have rounded ends, while others have a flange at one end for the purpose of guiding them in the raceways. The most widely used roller is of the parallel type having a length equal to its diameter and with flat and parallel ends. These are manufactured within 0·0001 in. of standard on diameter and within 0·0002 in. of standard on length. Balls are made within 0·0001 in. of standard both for diameter and sphericity, but it must be pointed out that the balls or rollers for any one bearing should be graded to considerably finer tolerances, in order to ensure even distribution of the load.

The tracks on the races are, of course, designed to suit the particular rolling elements with which they are to be used, while the other details of the races depend on whether radial and/or axial loads are to be dealt with by the bearing, and are also influenced by the method of mounting to be adopted.

The steels employed vary from maker to maker, but for small bearings a direct hardening chrome-carbon steel is usually used. For the larger sizes a mild steel that can be suitably carburised is preferred. In the latter the depth of case should be about 2 to 3 mm., although for large heavy-duty bearings it should be much deeper. The case must be of the correct carbon content to ensure the necessary hardness, and there should be a gradual merging of the case into the core to provide toughness for withstanding shock loads.

The hardness of the working surface for both types of material mentioned should be about 630 Brinell, or Diamond Hardness H.D.800 where bearings having maximum load-carrying capacity are involved. In certain applications which demand bearings made in non-corrodible steel the hardness is, of course, considerably lower, and the load-carrying capacity of the bearings in such cases is very much lower than that of the equivalent standard bearings.

Cages for spacing the rolling elements are usually of brass, bronze, or steel, and sometimes of rustless iron, duralumin, or "bakelite." Where reduction of weight to a minimum is essential, duralumin and "bakelite" have an advantage over the other materials. "Bakelite" cages are also proving extremely satisfactory for very high speeds where the bearing loads are not heavy.

Cages may be of solid construction, machined from bar, tube, or rough castings, or where malleable materials are used may be pressed out from sheet. With both methods of manufacture they can be in one or two pieces. Solid cages of two-piece construction are usually riveted together, but if they are pressed out the parts can either be riveted or held together by small claws formed on the individual parts and bent over in an appropriate manner. In certain roller, journal, and ball-thrust bearings the cages consist of annular-shaped flat plates, drilled to locate the rolling elements, fixed at a definite distance apart from one another by distance-pieces, and riveted together.

The cages must run concentrically with the rotating race of the bearing, and may be centred on the lips or shoulders of either of the races or on the rolling elements themselves.

BALL BEARINGS

The Single-row Rigid Ball Journal Type (Fig. 1).—This is one of the most widely used of all the types of anti-friction bearings. It has a single row of balls, and the running tracks are made to conform closely to the contour of these in order to give maximum support under load; but it is owing to this feature that it cannot accommodate any appreciable errors of alignment.

The balls can be assembled between the race tracks through gaps or filling slots provided at the sides of the races, and this allows up to a full row of balls to be accommodated. Alternatively a sufficient number of balls may be left out to enable a cage to be fitted. On bearings of this type the depth of the filling slots should not be great enough to extend to the bottom of the race tracks where they would catch the balls. At the same time, if bearings with filling slots are subjected to thrust load, there is some danger of damage to the balls occurring from this source.

The more widely adopted method of assembly is to put the races eccentric to one another and insert as many balls as possible in the crescent so formed. The races are then brought concentric with one another, the balls spaced evenly around the annular space and a two-piece cage fitted. Fewer balls can be accommodated by this method, but it has the advantage that the races are not weakened and bearings without filling slots will deal satisfactorily with some side thrust; in fact, they are frequently used in combination with roller journal bearings to locate shafts endways.

The Double-row Rigid Ball Journal Type (Fig. 2).—This has two rows of caged balls each running on separate tracks formed on the inner and outer races. The tracks are of similar form to those in the single-row rigid-ball bearings, but filling slots are provided for assembling the balls. These bearings are wider than the corresponding single-row bearings, but will not carry twice the load; and if this is beyond the capacity of the latter type it is often better practice to use a roller bearing.

The Double-row Self-aligning Ball Journal Type (Fig. 3).—This has two rows of balls each running on separate grooved tracks formed on the inner race. The inner surface of the outer race is made spherical, thus permitting the inner race and balls to swivel so that the balls will run freely without constraint despite lack of alignment.

The Single-row Self-aligning Ball Journal, Narrow Type (Fig. 4).—This is similar to the corresponding single-row rigid bearing shown in Fig. 1, but the periphery of the outer race is accurately ground spherical and fits into a seating of corresponding shape in an outer shell or housing. As it is of the same internal construction as the single-row rigid bearing and the self-aligning feature does not affect the standard curvature of the ball tracks, it has the same load-carrying capacity.

The Single-row Self-aligning Ball Journal, Wide Type (Fig. 5).—This is similar to the bearing ast dealt with, except that a wider shell is fitted in order to accommodate end covers fitted immediately alongside the bearing and within the spherical seating of the shell. These covers, therefore, swivel with the outer race on its seating, and thus maintain a fine running clearance with the rotating parts irrespective of the degree of mal-alignment, without gaping or fouling.

The Single-row Self-aligning Ball Journal, Wide Type with Taper Sleeve (Fig. 6).—The only difference between this and the preceding bearing is that the inner race is tapered in its bore to accommodate a split taper sleeve. As will be seen, the sleeve projects through the end covers, and the clamping nut is fitted on the outside so that the bearing can be mounted in position without exposing the working parts to dirt and moisture.

Taper clamping sleeves are also applied to the single-row rigid and double-row self-aligning ball bearings, shown in Figs. 1 and 3 respectively, when required.

The Single-row Angular Contact Type (Fig. 7).—In this type of bearing, as its name implies, the balls make contact with the sides of the running tracks, instead of with the bottom, as in the single-row rigid-ball journal bearing. The points of contact do not, therefore, lie in a direction perpendicular to the axis of the shaft, and this feature enables the balls to carry a higher percentage of thrust load. The bearing can be used to deal with either journal load or thrust load in one direction, or a combination of both. Unless there is a continuous thrust load in one direction in excess of the journal load, single-row angular contact bearings should be used in pairs, adjusted against one another to eliminate excessive slackness and to keep the balls in their correct positions in relation to the running tracks. The cage fitted to this type of bearing is a solid one-piece member, and

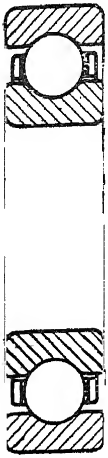


Fig. 1.—The single-row rigid ball journal bearing.

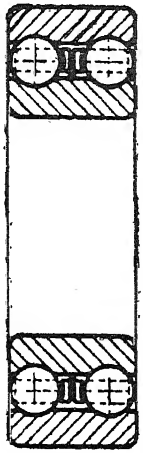


Fig. 2.—The double-row rigid ball journal bearing.

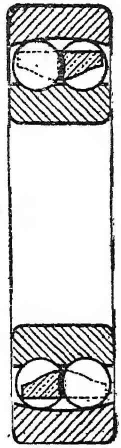


Fig. 3.—The double-row self-aligning ball journal bearing.

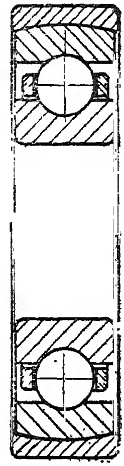


Fig. 4.—The single-row self-aligning narrow-type ball journal bearing.

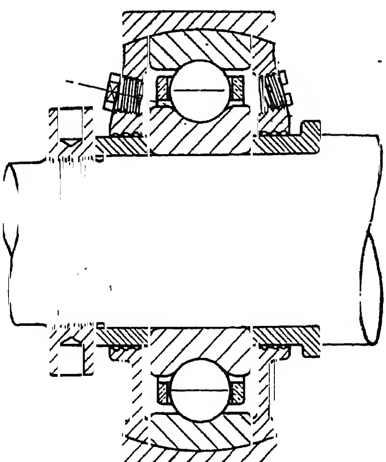


Fig. 5.—The single-row self-aligning wide-type ball journal bearing.

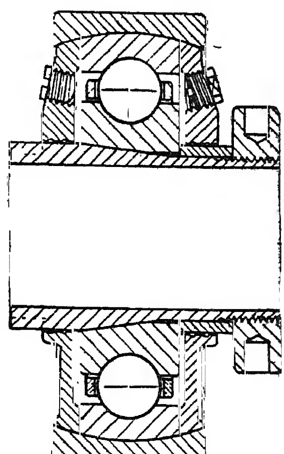


Fig. 6.—The single-row self-aligning wide-type ball journal bearing with taper sleeve and nut.

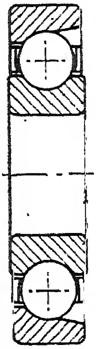


Fig. 7.

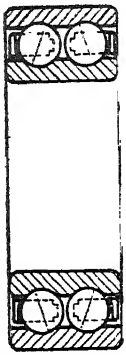


Fig. 8.

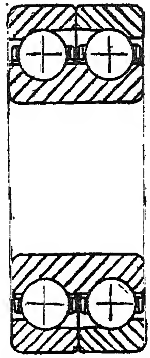


Fig. 9.

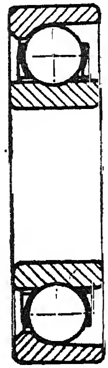


Fig. 10.

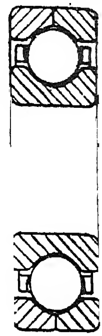


Fig. 11.

Fig. 12.

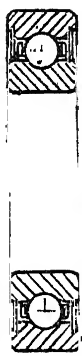


Fig. 13.

Fig. 7.—The single-row angular-contact ball bearing.
Fig. 8.—The double-row angular-contact ball bearing with one-piece races.
Fig. 9.—The double-row angular-contact ball bearing with two-piece outer race.
Fig. 10.—The magneto bearing.
Fig. 11.—The duplex bearing with split outer race.
Fig. 12.—The duplex bearing with split inner race.
Fig. 13.—The single-row rigid ball journal bearing with two end shields.
Fig. 14.—The single-row rigid ball journal bearing with one felt seal.
Fig. 15.—The single-row rigid aircraft control bearing with two end shields.
Fig. 16.—The single-row self-aligning aircraft control bearing with two end shields.
Fig. 17.—Single-row rigid ball journal bearings for torque tubes.
Fig. 18.—Ball-bearing control rod end with solid shank.

Fig. 15.

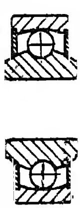


Fig. 16.

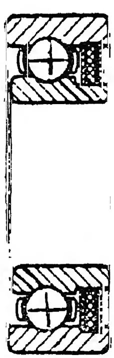


Fig. 14.

Fig. 17.

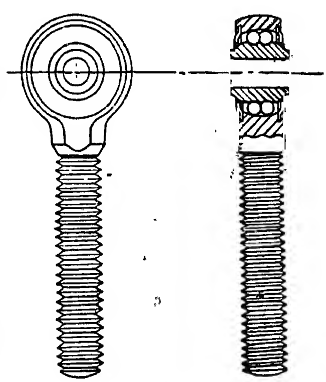


Fig. 18.

as the outer race is not detachable, the bearing can be handled as a unit. One shoulder in the outer race is partly cut away so that a greater number of balls can be assembled than in the single-row journal bearing.

Bearings of this type are frequently supplied in pairs pre-loaded together, either with their open sides facing one another or with their shouldered sides together, and they may also have distance-pieces between the two inner and outer races. They are also supplied paired together in tandem, so that the sum of their thrust capacities is available for dealing with heavy loads. The bearing components of these paired units are not always interchangeable, and should, therefore, be kept together as supplied.

The Double-row Angular Contact Type (Figs. 8 and 9).—There are a number of different designs meeting this description, but in all cases each row of balls runs on its own inner and outer tracks. Bearings are available with one-piece inner and outer races, and where these are used the balls are sometimes assembled through filling slots. These must be arranged, however, so that they will not catch the balls when thrust is applied. A bearing with one-piece races is shown in Fig. 8. Frequently these bearings have one-piece inner races and two-piece outer races, as shown in Fig. 9. This enables the maximum number of balls to be fitted without resorting to filling slots, but the two-piece outer race must be clamped firmly endways when the bearing is mounted. Double-row angular contact bearings are suitable for pure journal or thrust loads, or any proportion of journal and thrust load combined.

The Magneto Type (Fig. 10).—This is a small bearing similar to the single-row angular contact type (Fig. 7), but one side of the running track in the outer race is omitted, so that the race is detachable.

The Single-row Angular Contact Duplex Type (Figs. 11 and 12).—This type of bearing has two separate and distinct tracks formed on each race, and is thus enabled to take end thrust in either direction. Owing to this feature, the bearing has a small amount of end-play and is not adjustable. Duplex bearings can be used for thrust loads only or for combined journal and thrust loads, but in the latter case the amount of thrust load must always exceed the journal load, to ensure the balls are running on one set of tracks at a time. Bearings can be supplied with either two-piece outer races or two-piece inner races, as shown in Figs. 11 and 12. The two-piece race is, of course, detachable.

The Single-row Rigid Ball Journal Types with Protection Devices (Figs. 13 and 14).—To protect the working surfaces and to retain the grease with which they are filled during assembly certain of the smaller sizes of single-row rigid-ball journal bearings can be supplied with end shields, as shown in Fig. 13. These end shields consist of sheet-metal discs attached to the outer race and bored so that they make a running clearance with the shoulders of the inner race. Either one or two end shields can be fitted, but in the latter case it is not possible to replenish the grease lubricant. On certain applications, however, it is considered that the original supply will be sufficient to last the life of the machine on which the bearings are used. Bearings with end shields can be of the same external dimensions as the equivalent standard-type bearing.

Another type, originating in America and known as the "Grease Seal" bearing, incorporates a felt seal on one or both sides. Various designs of seal are in use, but Fig. 14 shows a typical arrangement. The seal, a felt ring, is held in position between two split-steel rings sprung into grooves in the bore of the outer race, and rubs on a plain diameter on the inner race at the side of the ball track. Certain bearings can be obtained with an end shield on one side and a grease seal on the other. Bearings of this type are generally of the same bore and outside diameter as the standard bearing, but are necessarily wider.

Types of Bearings Developed for Aircraft Controls (Figs. 15, 16, and 17).—Two ranges of bearings have been developed for use on aircraft, in positions such as control pulleys and hinges, where lubrication and protection is difficult to arrange.

The type shown in Fig. 15 is a single-row rigid bearing containing a full row of balls and fitted with two end shields. The other type, shown in Fig. 16, also has a full row of balls and two end shields, but the outer track is ground spherical so that a limited self-aligning feature is obtained. The shoulders on the inner

race are also of spherical form so that the efficiency of the protection is unimpaired by mal-alignment of the races. On both these types the external surfaces are treated to prevent corrosion, and during assembly they are filled with anti-freezing grease.

Fig. 17 shows a type designed primarily for use on tubes where the bore is necessarily large in comparison with the load. This is a single-row rigid bearing, which is not fitted with a cage and has races of extremely light section to keep the weight to a minimum. These bearings must be suitably enclosed to protect them and to retain the lubricant.

Figs. 18 and 19 show two types of ball-bearing control rod ends. The bearings contain two rows of balls running on separate inner tracks and a common spherical outer track, thus providing a self-aligning feature. End shields are fitted to exclude dirt and retain the lubricant, and the external surfaces are treated to prevent corrosion.

Single-thrust Type with Flat Seating (Figs. 20 and 21).—In this type of bearing the races are placed side by side and the balls, separated from one another by means of a cage, are sandwiched between them. In most cases grooved tracks are provided on the races for the balls, but for very light duties flat tracks, as shown in Fig. 20, are suitable.

Single Thrust with Spherical Seating and Seating Ring (Fig. 22).—This is similar to the type shown in Fig. 21, except that one race is provided with a spherical seating face which rests on a correspondingly shaped seating ring to compensate for out of squareness of the abutment of this race. Thrust bearings can also be obtained with their seating rings extended to form cylindrical housings enclosing their working parts.

The Double-thrust Type (Figs. 23, 24, and 25).—As their name implies, these are designed to take end-thrust in either direction. The type shown in Fig. 23 requires careful axial adjustment, when mounting, to ensure that both rows of balls are always in contact with their running tracks and at the same time to avoid initial load sufficient to cause overload when the working load is applied.

The danger of incorrect adjustment with the type shown in Fig. 23 can be avoided by using a bearing with a sleeve and nut, as shown in Fig. 24. The adjustment in this case is carried out by the manufacturer, after which the nut is locked in position. This enables the sleeve to be clamped solidly on the shaft, and no adjustment whatever is necessary by the user.

With the two preceding types the centre race is usually clamped in a stationary housing, the end races being rotating members, but in certain applications it may be more convenient to clamp the centre race on the shaft and centre the end races in the housing. When this is done, the end races can also be modified to rest on spherical seating rings. Such a bearing is shown in Fig. 25.

The Double-row Ball-thrust Type (Fig. 26).—These are designed and manufactured specially for dealing with very heavy loads, beyond the capacity of the single-thrust bearing. The rotating race is made in one piece and provided with two separate and concentric running tracks for the two rows of balls. The stationary race is made in two separate parts, each having a running track for one row of balls. Usually the parts of the stationary race are made with flat seatings, which are supported on a resilient washer, of lead or linoleum, in order to distribute the load between the two rows of balls.

ROLLER BEARINGS

Single-row Parallel-roller Journal Type (Fig. 27).—The use of rollers in a bearing instead of balls gives considerably higher capacity for carrying load, so that heavier loads may be imposed on a roller bearing than on a ball bearing, without increase of external dimensions, or alternatively the same load can be carried by a smaller bearing.

The standardised and most popular type of parallel roller bearing has rollers whose length is equal to the diameter and which run on cylindrical and concentric tracks. Fig. 27 shows the most generally used construction, in which the rollers

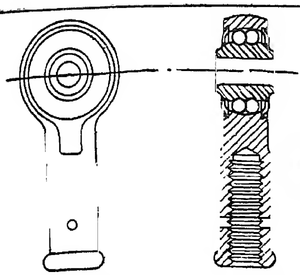


Fig. 19.—Ball-bearing control rod end with hollow shank.

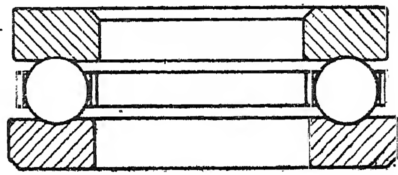


Fig. 21.—Single-thrust bearing with grooved tracks.

Fig. 20.—Small extra-light thrust bearing with flat tracks.

Fig. 22.—Single-thrust bearing with spherical seating ring.

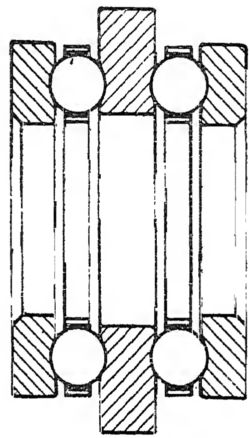


Fig. 23.—Rigid double-thrust bearing.

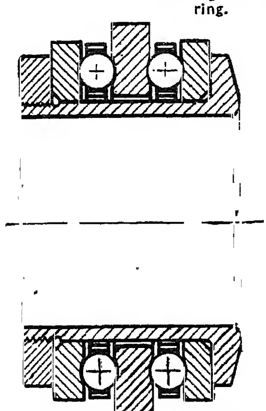


Fig. 24.—Rigid double-thrust bearing with sleeve and nut.

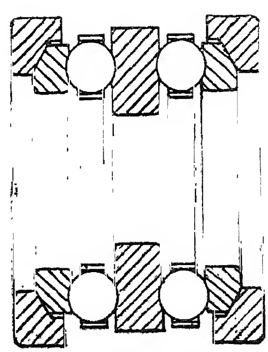


Fig. 25.—Double-thrust bearing with spherical end-seating rings.

run and are guided in a channelled track formed on the inner race. As the outer race is a plain annulus, the bearing will not locate the shaft endways.

Double-lipped Parallel-roller Journal Type (Fig. 28).—In this type of bearing both the inner and outer races are of channel section so that it can be used

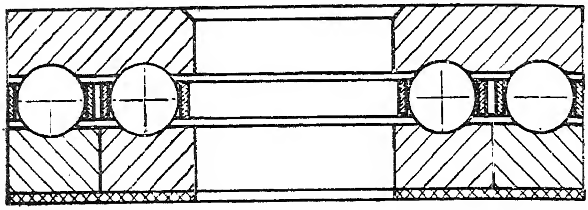


Fig. 26.—Special double-row thrust bearing on linoleum washer.

for locating parts sideways where there is no definite and continuous end thrust. Owing to the nature of its construction fewer rollers can be accommodated than in the corresponding standard type referred to above, so that its load capacity is not so high.

Double-lipped roller bearings can be made with the outer surfaces of their outer races ground spherical, and can be supplied as self-aligning bearings having the same features as the ball bearings shown in Figs. 4, 5, and 6.

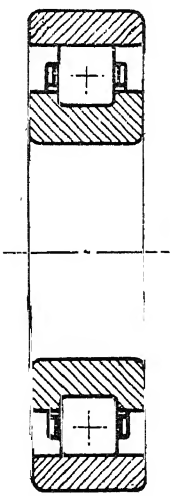


Fig. 27.—Standard pattern single-row rigid roller journal bearing.

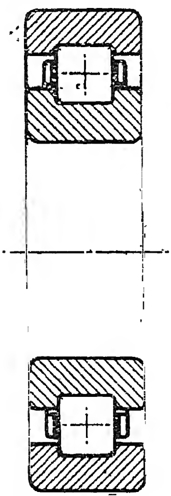


Fig. 28.—Single-row rigid double-lipped roller journal bearing.

Parallel-roller Journal Types with Special Lip Arrangements (Fig. 29).—The parallel-roller bearing can be supplied in a wide variety of forms which consist of modifications to the lip arrangements on the races without involving alteration to the external dimensions. A number of these are shown in Fig. 29. These modifications to the basic type are extremely useful, and are often incorporated in designs to facilitate assembly and dismantling of the machine parts. It will also be seen that a roller bearing into which can be assembled the maximum number of rollers, either with or without a cage, can be arranged to deal with location duty where this is required.

The Needle-roller Journal Type (Fig. 30).—As its name implies, the needle bearing contains rollers of small diameter and, comparatively, of considerable length. Standard sizes are from 2 mm. to 4 mm. in diameter and with a length to diameter ratio between 5 : 1 and 10 : 1.

Needle bearings are essentially journal bearings, as, owing to the proportions of the rollers, they are not suitable for dealing with thrust loads or even for taking ordinary location duty. Consequently only one of the races, usually the outer one, is provided with lips at the sides of the track, and these are for guiding the ends of the rollers. The other race is made a plain cylindrical member.

No cage is fitted to the needle-roller bearing, the annular space between the tracks being almost completely filled with the needle rollers. Needle rollers are made with various shapes of ends, but the hemispherical end is the one most commonly used.

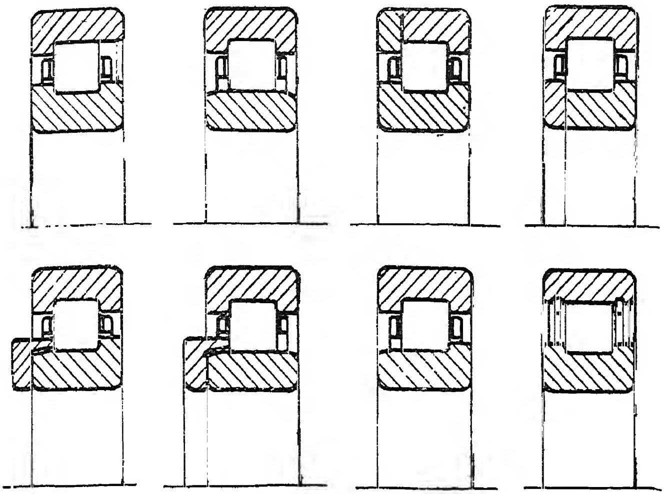


Fig. 29.—Special lip arrangements for cylindrical roller journal bearings.

0.—Needle-roller
ournal bearing.

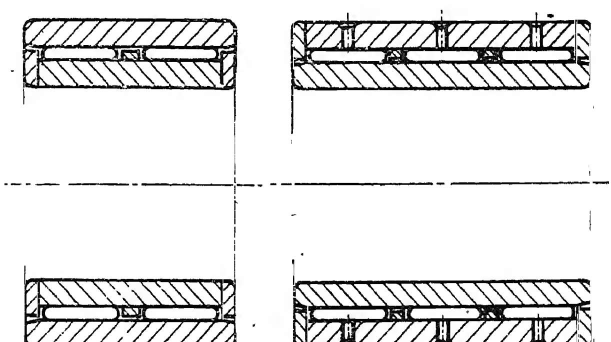


Fig. 31.—Special needle-roller bearings with two and three rows of rollers.

Multi-row Needle-roller Types (Fig. 31).—To meet special requirements and to deal with loads beyond the capacity of the standardised single-row bearings, needle-roller bearings can be made with more than one row of rollers. Typical examples are shown in Fig. 31. It is essential for the rows of rollers to be separated from one another and to be guided at their ends by hardened and ground faces. Distance-pieces and end plates may be used for this purpose, or the guiding and

locating faces can be formed on parts made integral with the tracks. Where space limitations demand it, the races can be omitted and the rollers run direct on the machine parts, provided the latter can be correctly hardened and accurately ground.

Needle-roller Type with Retained Rollers (Figs. 32 and 33).—If the races of the standard type needle bearing become displaced during handling of the bearing, there is danger of the rollers falling out. Bearings are now available

Fig. 32.—Needle-roller journal bearing with retained rollers.

Fig. 36.—Taper-roller journal bearing (normal angle).

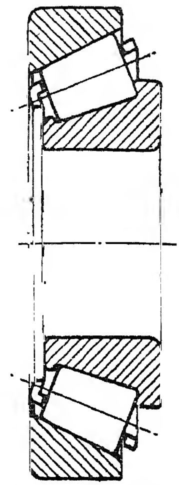


Fig. 37.—Taper-roller journal bearing (steep angle).

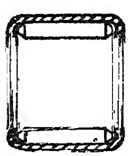


Fig. 33.—Needle-roller journal bearing with retained rollers.

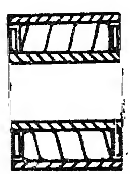


Fig. 34.—Flexible roller journal bearing.

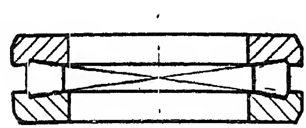


Fig. 35.—Taper-roller thrust bearing.

n which provision is made for retaining the rollers in one of the races. An example of this type is shown in Fig. 32, and it will be noted that the needle rollers used are trunnion ended, this feature greatly facilitating retention.

Fig. 33 shows another type of needle-roller bearing with retained rollers. This is of American design and manufacture. The outer race is a thin cylindrical shell with its ends turned in to retain the rollers, which have conical ends. This bearing has the advantage that it requires very little space, but it is essential to provide an accurately bored housing to support the outer race correctly.

The Flexible Roller Type (Fig. 34).—In this type of bearing the rollers are formed from rectangular sectioned strip which is closely wound into a helix,

later heat treated and accurately ground on its periphery. Bearings of this type can be obtained with short and also with comparatively long rollers, and these are assembled with left-hand and right-hand helices alternately. This feature prevents the lubricant from being forced out from the bearing at one end, and the claim is made that it ensures perfect distribution of the lubricating oil over the working surfaces. It is also claimed that the resilience and flexibility of the rollers enable the bearing to absorb shock loads and distribute them over its entire surface. At the same time, as the rollers are hollow, the capacity of this type of bearing is comparatively low.

The Taper-roller Type (Figs. 35, 36, and 37).—Bearings of this type come into two distinct classes: those intended solely for thrust load as in Fig. 35, and those designed for combined journal and thrust loads (Figs. 36 and 37). In all cases the tracks and rollers are conical in shape and must be constructed on true geometric principles, which require the apices of the conical working surfaces to coincide at a single point on the axis of the bearing or the axis produced.

The bearings can be manufactured with short, medium, or long rollers, and if the parts are of the highest degree of accuracy as regards both taper and dimension, the rollers will make contact throughout their length and run without slip occurring, so that conditions for maximum load-carrying capacity are met.

Bearings with the steeper angle of the raceways, as shown in Fig. 36, give a high ratio of thrust to journal capacity, and are, therefore, particularly suitable where the thrust load predominates.

Due to the tapered construction of these bearings, a pure radial load gives rise to a thrust reaction which must be taken by another bearing mounted in the opposite direction. For this reason taper-roller combined radial and thrust bearings are usually mounted in pairs. This thrust reaction is, of course, transmitted through the rollers, and presses their large ends against the retaining lip on the inner race with considerable pressure, so that this type of bearing is not the most suitable for use at high speeds.

In the case of the thrust bearings (Fig. 35), the reaction due to the taper sets up an outward force on the rollers, which again is taken on lips provided on the races; but the resulting friction force is much greater owing to the necessarily steeper angle of taper.

The Double-row Self-aligning Roller Type (Fig. 38).—This is similar in construction to the double-row self-aligning ball bearing shown in Fig. 3, but the balls are replaced by barrel-shaped rollers, thus giving considerably increased capacity. The rollers are of two types, those having their maximum diameter half-way along their length and those whose maximum diameter is slightly off centre.

A bearing fitted with the latter type of roller is shown in Fig. 38. In this case the double inner tracks are designed to conform closely to the barrelled shape of the rollers, but the outer track is made spherical, and the rollers do not make contact with it along their complete length. As the rollers are of larger diameter at one end than the other, a thrust component is set up similar to that which occurs with the taper-roller bearings, and this is taken on the central lip separating the two inner tracks.

Miscellaneous Special Roller Journal Bearings (Figs. 39, 40, and 41).—Fig. 39 shows one of the special roller crankpin bearings designed for motor-cycle engines. The bearing manufacturers often supply the crank pins, which have channelled tracks formed direct on them for the rollers. A cageless-type bearing is common practice, as this gives maximum capacity within the limiting dimensions available, and a plain cylindrical outer race is provided for pressing into the bore of the connecting rod.

Special rollers and cages are frequently made as complete units to meet special requirements, particularly where the space is not sufficient to accommodate the more conventional type of bearing with inner and outer races. Correctly hardened and accurately ground tracks must be provided on the machine parts for the rollers, however. Two examples are shown in Figs. 40 and 41; but there are considerable variations in the designs of the cages which are sometimes fitted with long rollers and alternatively with two or more rows of short rollers.

A number of the types described, for example ball journal bearings with end shields and/or felt seals, are of a special nature, and made only when ordered in quantity, so that in many cases complete ranges of sizes may not be available. The advantages resulting from the use of standard bearings cannot be over-stressed. The majority are continuously produced by a number of manufacturers, and in most cases can be obtained at short notice either from them or from

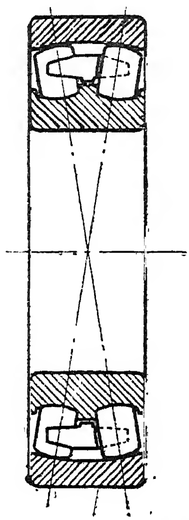


Fig. 38.—The double-row self-aligning barrel-roller bearing.

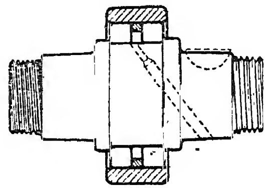


Fig. 39—Double-row motor-cycle crankpin bearing.

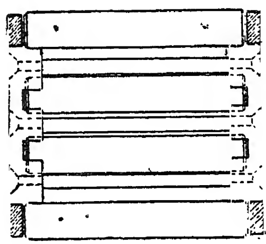


Fig. 40.—Special cage with long rollers.

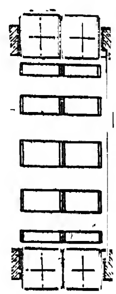


Fig. 41.—Special cage with two rows of short rollers.

Bearing Factors. This is invaluable in the event of a breakdown occurring. Another advantage is that standard bearings are generally considerably cheaper than special or even semi-special bearings.

DUTIES

It is not possible to formulate hard-and-fast rules stating when individual types of bearings should be used which will meet all conditions of duty. Correct bearing selection can be made only after full consideration of the particular working conditions in the light of past experience. At the same time, certain broad principles can be laid down and will serve as a useful guide.

Rigid Bearings.—Where accurate alignment can be obtained and maintained between the race seatings rigid bearings should, of course, be used. This is generally the case where the bearings are housed in a common casting or forging, and also where the parts forming the housings can be accurately machined, and registered in position by dowels, spigots, or similar devices. Examples are automobile gearboxes and axles, electric motors, industrial reduction gears, and machine-tool spindles, to name only a few. Where a shaft is to be carried on two journal bearings, no advantage is obtained by using a rigid bearing at one end and a self-aligning bearing at the other end, and if the alignment is not accurate self-aligning bearings should be used in both positions.

Self-aligning Bearings.—These must be used in cases where the bearing seatings cannot be lined up accurately; as for example, where the bearings are housed in independent pedestals mounted on separate supports, or where the distance between the bearing centres is so great that there is doubt whether the alignment will be maintained.

Self-aligning thrust bearings are sometimes used in conjunction with rigid journal bearings. Such an arrangement is often useful where the abutment for the stationary race of the thrust bearing is separate from the main housing, as out of squareness of the former can be accommodated.

Self-aligning journal bearings are frequently used at outboard positions for shaft extensions, irrespective of whether the other bearings on the shaft are of the rigid type or not. While this has the advantage that out of squareness of the outboard housing can be accommodated, it is essential to ensure that the bores of all the bearing housings are accurately lined up horizontally and vertically.

It must be stressed that no self-aligning bearing will operate satisfactorily under any serious load where the self-aligning feature is required to operate continuously, as will occur with a bent shaft or where the conditions are such that whirling of the shaft develops.

Taper-sleeve Bearings.—Bearings with taper clamping sleeves are intended for use where it is not possible to machine the shafts to provide really accurate seatings or abutments for clamping the inner race endways. For a given shaft diameter their use involves a larger size of bearing, and they are not the most suitable type for high-speed conditions or where severe vibratory loads are involved.

Speeds.—For applications involving extremely high speeds and negligible loading, the most suitable types of bearings are single-row rigid ball journal bearings, and single-row angular contact bearings of the type intended to take combined journal load and thrust in one direction (see Figs. 1 and 7 respectively). In special cases the bearings may have cages made in "bakelite."

Very little information is published regarding the maximum speeds of standard ball and roller bearings, and it is impossible to lay down hard-and-fast figures for individual bearings, as the maximum speed at which satisfaction can be obtained depends to a considerable extent on the accuracy of the mounting and the efficiency of the lubrication.

Fig. 42, which is based on information published by the Hoffmann Manufacturing Co., Ltd., will serve as a guide, and will at least indicate when the speed is approaching a high figure for a given size of bearing. Intermediate sizes of bearings may be dealt with by interpolation, and consideration should be given to the relative outside diameters of the bearings as well as to their bores. It must be emphasised that the figures obtained from the upper curve do not by any means represent the maximum speeds at which ball and roller bearings can be run even if lubricated by grease, and a further increase is possible with oil lubrication. However, unless users have previous experience of similar conditions on which to draw, they are advised to consult the bearing manufacturers when the speed for a particular bearing approaches the figure given by the top curve.

Light and Medium Radial Loads.—The decision as to whether ball or roller bearings are used may be influenced, not only by consideration of the working conditions, but by some special feature required in the design of the machine, such as ease in assembly and dismantling. For general purposes, however, it may be said that where light or medium radial loads of a steady nature are involved ball journal bearings can be used. For a given shaft size they are cheaper than roller bearings, and if necessary they can be modified to run satisfactorily at rather higher maximum speeds.

Where the loads are subject to sudden variations and shock conditions are present roller bearings are preferred, owing to the larger areas of contact of their working parts. Standard-type roller bearings are also particularly useful where out-of-balance loading is involved or where the direction of the load is continuously changing. Such conditions tend to set up creep of the outer races on their seatings, and this can only be overcome by making these races an interference fit (see section on "Mounting").

Heavy Radial Loads.—Roller bearings should always be used where the loads are heavy for the shaft size under consideration. In cases where the speed is relatively slow, needle-roller bearings may be used, and these have proved very successful where the load and/or speed is subject to fluctuation. They are also well suited to applications where the shafts are only required to oscillate, even although the loads may be very heavy.

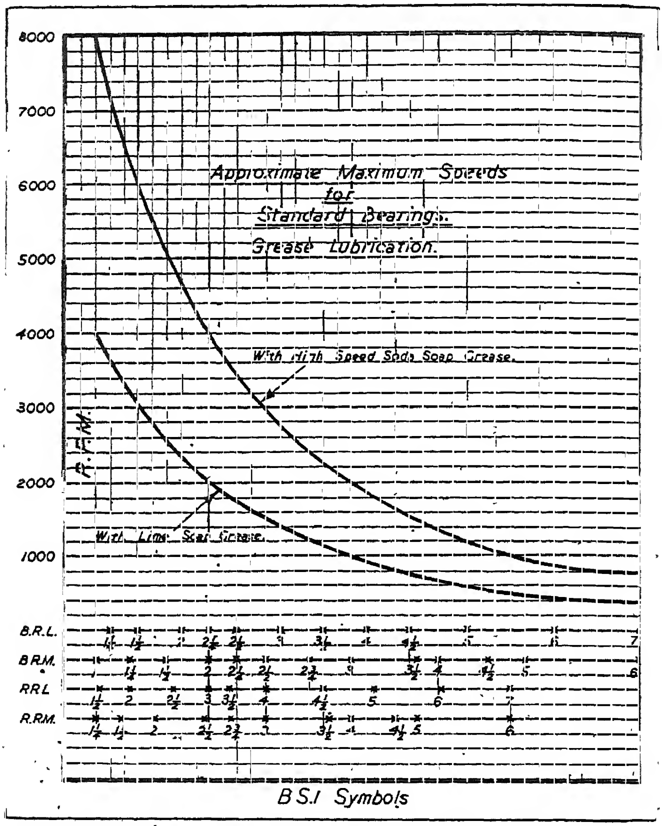


Fig. 42.—Curves giving speeds for standard ball and roller journal bearings.

Light Thrust Loads.—It is generally advisable when thrust loads are present in an application to consider these in conjunction with the radial loads. In many cases where rigid ball journal bearings of the "no-gap" type are used for dealing with the radial loads the thrust, if only light, can be taken on one of these bearings. This is normal practice in automobile gearboxes.

Where the journal loads are sufficiently heavy to require cylindrical-type roller bearings light end thrust may be taken on a ball-location bearing mounted adjacent to one of the roller bearings. Ball-location bearings are of the same

construction as standard single-row rigid ball bearings, but are made smaller on outside diameter, so that when mounted in housings bored to suit standard journal bearings they are clear radially, and are thus unable to take journal load.

In cases where cylindrical roller journal bearings are required and the thrust is not definite or continuous, but only of an intermittent nature such as met with in normal location duty, one of the roller bearings can be of the type with two lips on both its inner and outer races, and may be used for controlling the shaft endways. Such bearings are frequently used on lineshafting, horizontal electrical machinery, vibrating screens, and the hubs of commercial vehicles, to name only a few applications.

Double-row self-aligning ball journal bearings should not be used for dealing with end thrust without first referring to the makers. Under appreciable thrust the load would be thrown on to one row of balls, and owing to the small angle of the outer track severe wedging would occur.

Barrel-roller bearings, however, are frequently used for dealing with end thrust in combination with radial load.

Medium Thrust Loads.—Although the use of thrust bearings is sometimes essential, modern practice tends towards the use of angular contact bearings of the ball or taper-roller type for dealing with the radial as well as the thrust loading on the shaft. This effects considerable economy in space over the older arrangements incorporating separate journal and double-thrust bearings, and often shows an appreciable reduction in first costs.

Angular contact bearings of the type shown in Fig. 7 are particularly suitable where the speeds are high, and when used in pairs correctly adjusted together will deal with any proportion of journal and thrust load.

Duplex bearings, shown in Figs. 11 and 12, can be used for combined journal and thrust loading or thrust only, but in the former case the thrust must always exceed the journal load.

Heavy Thrust Loads.—Where these occur at slow speed or under oscillating conditions or partial rotation only, thrust bearings are generally the most suitable type to use, and are essential for such applications as railway turntables, swing bridges, etc. At higher speeds angular contact bearings are generally to be preferred, but if the load is beyond the capacity of a single bearing it may be possible to use two bearings of the type shown in Fig. 7 in tandem, so that the sum of their thrust capacities is available. Where such an arrangement is considered necessary it is advisable to consult the bearing manufacturers.

Diametric Clearance.—A certain amount of diametric or running clearance is necessary in ball and parallel roller journal bearings to allow for expansion of the inner race or contraction of the outer race which may be caused by interference fits or variations of temperature. These bearings are made with three different ranges of diametric clearance, which are known as "0," "00," and "000." fits or sometimes as "X," "Y," and "Z" fits.

"0" fit bearings have the smallest amount of diametric clearance, and should only be used in cases where freedom from all shake is required in the assembled bearing and there is no possibility of the initial clearance being eliminated by external causes.

The intermediate grade, "00" fit, is the most suitable for ball bearings intended for general engineering applications and may be regarded as the standard fit. Roller bearings require a little more clearance than ball bearings, and for these the "00" fit should be regarded as equivalent to the "0" fit ball bearing.

"000" fit bearings have the greatest amount of diametric clearance, and this is the standard fit for roller bearings used in general engineering. It should always be used when both the inner and outer races are made a heavy interference fit, or when external heat may be transmitted to the inner races of the bearings.

High-temperature Conditions.—The maximum temperature at which entirely standard ball and roller bearings will run depends on the steel used by the manufacturers and the heat treatment adopted. Temperatures in excess of approximately 250° F. or 120° C. may cause slight softening of the working surfaces, and there is danger of distortion of the races and rolling elements occurring.

Users are therefore advised to consult the bearing manufacturers if this figure

is likely to be reached. For running at very high temperatures in excess of 400° F., bearings in special alloy steels can be supplied, but as these cannot be hardened to the same degree as the standard steels, there is an appreciable drop in load-carrying capacity.

Preloaded Bearings.—In a ball or roller bearing under load deformation occurs at the working surfaces in contact. The amount of deformation is not in direct proportion to the load imposed, the rate of increase being higher in the initial stages of loading and decreasing appreciably as the load increases.

Preloading consists of applying an initial permanent load to the bearings, either during manufacture or by means of some special feature in the design of the machine, of sufficient magnitude to take up the low-load deflection. Thus

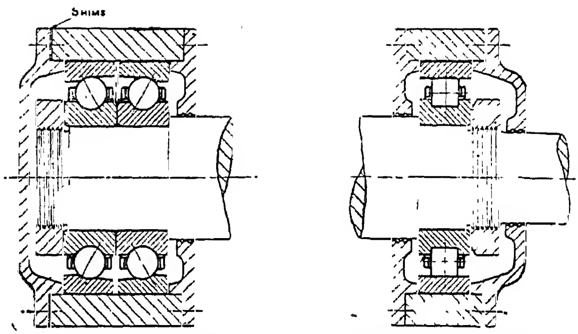


Fig. 43.—Ball bearings preloaded and adjusted by means of shims.

when the working loads are imposed the amount of deformation that takes place is very small and maximum rigidity is obtained.

The principle is applied essentially to angular contact bearings of the ball or taper-roller type, and can also be applied to double-row barrel-roller types, where the outer races are made in two parts. It is extremely useful on machine-tool spindles, where maximum rigidity is essential.

Figs. 43, 44, and 45 show alternative methods of preloading applied to angular contact ball bearings. In Fig. 43 the degree of preload is arranged by means of shims between the flange of the end cover and the adjacent face of the housing. Considerable experience is necessary in preloading bearings by this method, as there is danger of overloading them.

The difficulty with the arrangement in Fig. 43 can be avoided by using bearings paired up by the manufacturers to form units which when clamped firmly endways give the correct preload.

In the third arrangement (Fig. 45), the preloading is obtained by means of spring pressure. The amount of preload can be controlled and can be modified readily by using springs of different stiffness.

The arrangement shown is one commonly used on high-speed internal grinding spindles, where the maximum degree of accuracy is required.

SIZES

Ball and roller bearings are made to both English and metric dimensions, and cover a wide range of shaft sizes. Most types can also be obtained in two or more of the series known as Extra Light, Light, Medium, and Heavy, and for a given diameter of shaft it may be possible to obtain as many as four different bearings with the same bore and all of the same type. The outside diameters and widths of these will vary, being a minimum for the Extra Light Series and a maximum for the Heavy Series.

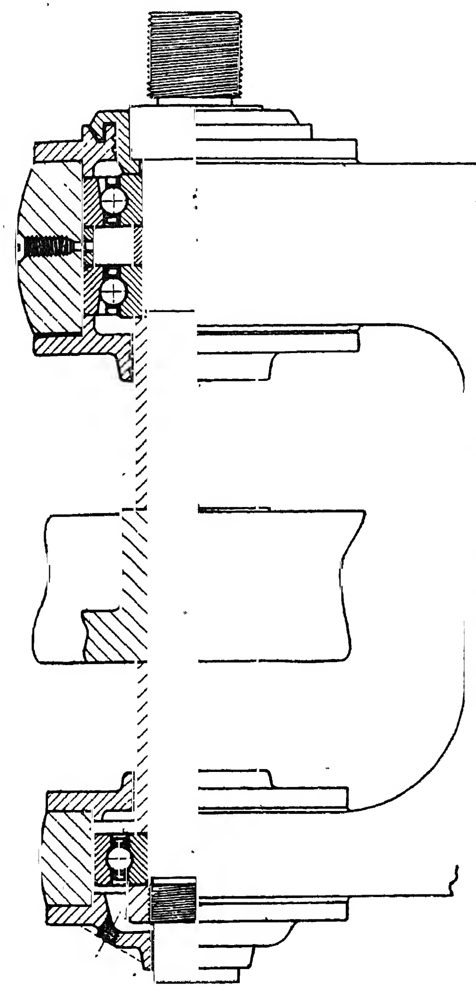


Fig. 44.—Angular-contact ball bearings paired back to back and preloaded.

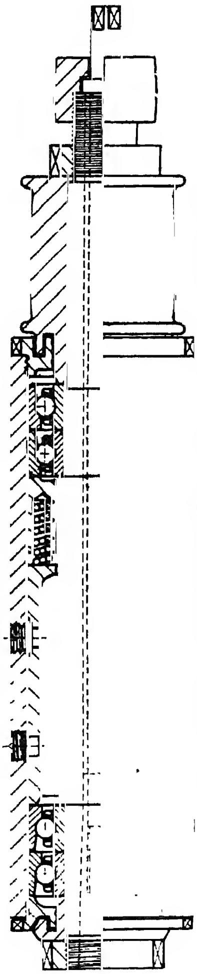


Fig. 45.—Angular-contact ball bearings preloaded by means of spring pressure.

The British Standards Institution have issued " Specification No. 292, 1927," covering the external dimensions and tolerances for ball journal and thrust bearings and also for parallel-roller journal bearings, and it is possible to interchange a bearing of one make with the corresponding bearing of another make without altering the shaft or housing.

The dimensions of British Standard Ball and Roller Bearings of the Metric Series agree with I.S.A. Standards with very few exceptions, and on the important dimensions, namely bore and outside diameter, the tolerances of B.S.I. bearings are in most cases finer.

The following tables give the dimensions and makers' symbols for the more popular sizes, types, and makes of ball bearings and parallel-roller bearings. Single-row angular contact bearings, including the duplex type, have the same external dimensions as the corresponding ball and roller journal bearings.

The convention when specifying the external dimensions of anti-friction bearings is to put them in the order:

Bore × Outside diameter (O.D.) × Width.

With regard to the footnote in Table 9—thrust bearings of the type " A " are fitted with races having equal bores and outside diameters, while in type " B " there is one large and one small race. (See " The Mounting of Thrust Bearings.")

MOUNTING

Seatings.—The seatings for the races must be parallel, truly circular, and accurately machined to fine limits. Also the parts on which the seatings are formed must be of sufficiently robust construction to support the races without risk of distortion, either under load or when the machine parts are being assembled and fixed in position.

Split housings should be avoided wherever possible, as a badly fitting cap will readily distort the races. Where a split housing is essential, however, the final machining of the bearing seating should be carried out with the cap registered and bolted in position.

Bearings should not be fitted directly into housings or casings of aluminium alloy or similar soft metals, where the loads are heavy or where there is considerable shock load. Under these conditions a hard-metal liner should be inserted in the housing.

Abutments.—Abutments for the races of both journal and thrust bearings must be true and square with the axis of rotation and must be free from all burrs.

For thrust bearings the effective abutment faces should extend at least to the pitch circle diameter of the balls, or approximately over half-way across the faces of the races.

In the case of journal bearings they should extend past the chamfers or unground radii on the corners of the races, so that there is no danger of the latter being canted.

A useful guide for journal bearings is:

Minimum diameter of inner race abutment = Bore of bearing + 4 × corner radius.

Maximum bore of outer race abutment = Outside diameter of bearing − 4 × corner radius.

For cylindrical-type roller bearings with lips on both the inner and outer races, used for location duty where momentary end thrust is likely to occur, the abutments should be of sufficient depth to extend beyond the roller tracks and thus support the lips against shear stress. At the same time particular care must be taken in such cases to ensure that the abutments are true and flat.

Where rigid bearings are involved and accurate alignment therefore essential, it is an advantage to be able to bore the housings straight through. In such cases the abutments for the outer races, where required, can be provided by loose end covers spigoted into the bore of the housing.

If bearings with taper clamping sleeves are used to deal with appreciable end thrust, it is not satisfactory to rely on the grip of the sleeve on the shaft for transmitting the thrust to the bearing. An abutment should be provided

for the end of the sleeve, and this can be in the form of a loose collar pinned in position.

Where clamping nuts are involved they should where possible be arranged to tighten up against the direction of rotation. It is a definite advantage if the nuts can also be locked after tightening.

Creep.—This is the name given to the slow rotation of a race relative to its seating. It has nothing whatever to do with the friction in the bearing.

In thrust bearings creep is due to out of squareness of one race. This causes uneven distribution of the load over the balls, and the point of maximum load, moving round in relation to the mating race, causes it to creep. Interference fits will not prevent creep of thrust races, and the only remedy is to ensure that the abutments are true and square with the axis of rotation. Unless there are special reasons the races of thrust bearings are invariably made a push fit.

In the case of journal bearings creep is due to the direction of the load constantly changing relative to a race which is slack on its seating or only a push fit. Under these conditions the race will rotate relative to the seating with a combined sliding and rolling action, and if allowed to continue wear will develop and the condition will be accentuated.

Keys, cotter pins, and similar devices are of no avail against creep and will eventually wear away under the constant chafing. The only remedy so far as journal bearings are concerned is to make races liable to creep a definite interference fit on their seatings.

Under a steady load there is no tendency for the stationary races to creep, and they are, therefore, usually made a push fit on their seatings. In special cases, however, or where out-of-balance loading is present, it may be necessary to make both the inner and outer races an interference fit.

Where races are made an interference fit, they should be pressed firmly against suitable abutments during mounting and preferably clamped. Clamping is essential where the bearing is required to locate in both directions.

Seating Limits.—The limits to which race seatings should be made in order to give the correct fit depend on the nature of the application, the material from which the seating components are made, and the make of bearing in use.

There are no standardised limits for the seatings of ball and roller bearings, and a comparison of the recommendations by the various makers shows wide variations. It must be stressed, particularly where interference fits are involved, that it is not satisfactory to work to the standard recommendations of one maker when fitting bearings of another make.

Interference fits cause expansion of inner races and contraction of outer races, and thus to some extent will reduce the diametric slackness in the bearing. The amounts of diametric slackness provided initially in ball and roller bearings are not the same for all makes, even if of one size and one particular grade of fit.

Users, therefore, should follow closely the individual makers' recommendations, and on applications where a heavy interference is required or where both inner and outer races are to be an interference fit should approach the makers who will advise suitable limits and also where necessary offer bearings with increased diametric slackness.

The amount of interference may vary from nothing in the case of small ball bearings to as much as 0·002 in. in the case of large heavily loaded bearings.

Taper-roller bearings can be made a heavier interference fit on their seatings than the standard-type ball and roller bearings as, owing to their construction, they are not subject to the limitations imposed by diametric slackness, which is determined independently by the adjusting device.

Mounting for Stationary Races of Journal Bearings.—No single length of shafting or single component should be located endways by more than one bearing in each direction, and in many cases location in both directions can be dealt with by the same bearing.

Fig. 46 shows a rotating shaft carried on two ball journal bearings, the inner races being an interference fit and clamped. One of the stationary races is shown held endways so that this bearing will locate the shaft.

It is essential that the other stationary race be made a nice push fit on its seating and left free endways. The end clearances provided must be sufficient to accommodate expansion of the shaft and/or cumulative tolerances of machined

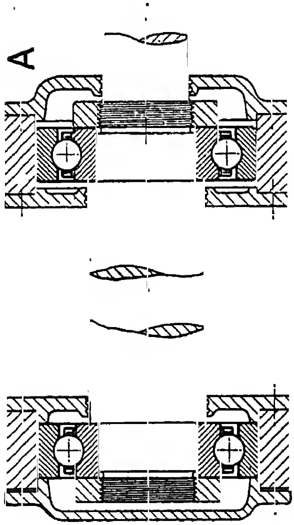


Fig. 46.—A shaft supported on two rigid ball journal bearings.

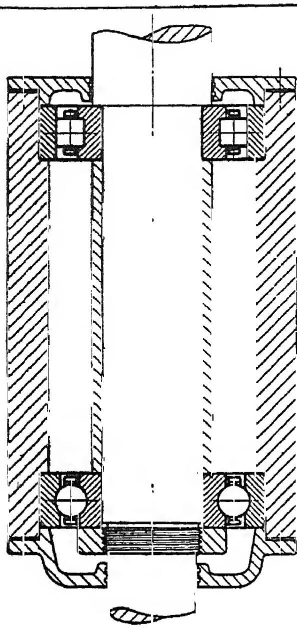


Fig. 47.—A shaft supported on one ball and one roller journal bearing.

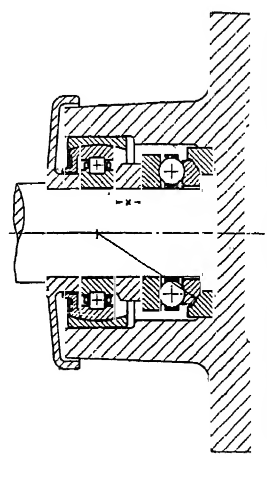


Fig. 48.—A footstep arrangement incorporating a self-aligning roller journal and ball thrust bearing.

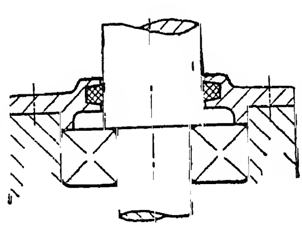


Fig. 49.—Protection incorporating a felt seal.

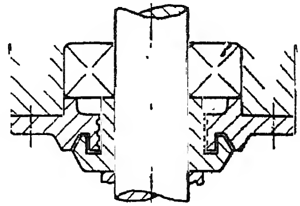


Fig. 50.—Labyrinth and thrower protection for dusty conditions.

components, so that the race can take up its correct position in relation to its opposite member without setting up permanent end thrust on both the bearings.

This principle is applicable to all ball or roller journal bearings whose races are closely controlled endways in relation to one another through the medium of the rolling elements, where such bearings are not required to locate endways.

In Fig. 47 a standard-pattern roller journal bearing is used in one position with a ball journal bearing in the other. It will be noted that where roller bearings of this type are involved the races can be made an interference fit, and clamped endways without any danger of imposing permanent end thrust on the bearings.

The Mounting of Thrust Bearings.—In the majority of single-thrust bearings the stationary race is made larger, both in the bore and on the outside diameter, than the rotating race. The housing must be bored true and concentric to fit the outside diameter of the large race, and will, therefore, clear the rotating parts, while the shaft must be made to suit the small race, and will, therefore, clear the stationary race by virtue of its larger bore.

Some extra-light series single-thrust bearings and the smaller sizes of the light series have identical races, and both should be centred on the shaft and left clear radially on their outside diameters. The bores are ground out slightly above standard size to permit the shaft to revolve freely in the stationary race.

When a thrust bearing is mounted on the end of a shaft the latter should extend through the bearing sufficiently to centre the ball cage. This ensures the balls are in their correct positions on the tracks and assists assembly.

If a self-aligning journal bearing and self-aligning thrust bearing are mounted together in a common housing as shown in Fig. 48, they must be spaced correctly so that they swivel about a common centre if a true self-aligning feature is to be obtained.

PROTECTION

It is essential to protect bearings against dirt and moisture, and wherever possible they should be completely enclosed.

If shafts are required to extend through the housings, end covers must be provided, and where they approach the shafts they should be made as broad as possible. If rigid bearings are used, the end covers should be bored about 0·010 in. larger than the shaft diameters. A series of grooves turned in the bore of an end cover will form an effective seal when filled with grease, and will be sufficient for normally clean and dry conditions.

If loose end covers are used they should be spigoted into the bore of the housing to ensure concentricity of their bores with the shaft.

Where self-aligning bearings are used with rigid covers larger clearances are necessary in the bores of the covers, to ensure the self-aligning feature is not impeded by fouling of the shaft, and to provide an effective seal felt washers are often fitted (see Fig. 49). The lubricant should have access to the felt, as otherwise it is liable to harden and wear the shaft. As this tendency is aggravated by dust or grit, this form of protection is not suitable for dirty conditions.

For wet and/or dirty conditions a labyrinth seal, incorporating a rotating thrower, is recommended. Fig. 50 shows an arrangement suitable for dusty conditions, while for wet and dirty conditions the arrangement in Fig. 51 has proved satisfactory.

Where a vertical shaft extends through the top of the bearing housing, the arrangement in Fig. 52 is recommended, and this is suitable for excluding dust or water.

On vertical shafts special consideration must be given to the retention of the lubricant, and the arrangement in Fig. 53, incorporating an internal thrower and lipped end cover, will retain grease and also oil if not flooded.

On horizontal shafts where oil lubrication is used it may also be necessary to use an internal thrower and lipped end cover, and the arrangement in Fig. 54 is suitable if the oil level is below the lowest point of the end cover bore.

In totally enclosed mechanisms where end covers are unnecessary it is advisable to fit chip shields adjacent to the bearings, to prevent metallic chips from gears, etc., gaining access to the working parts. The chip shields can be in the form

of simple washers clamped against the inner races of the bearings and made to such a diameter that they make a running clearance with the bore of the outer race.

LUBRICATION

An adequate supply of a suitable lubricant is essential if satisfaction is to be obtained with ball and roller bearings. This is required for lubricating the

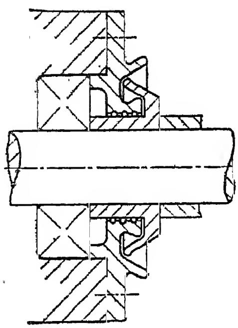


Fig. 51.—Labyrinth and thrower protection for wet conditions.

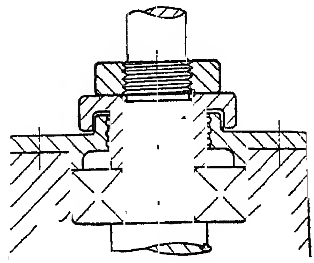


Fig. 52.—Protection for vertical shaft mounting.

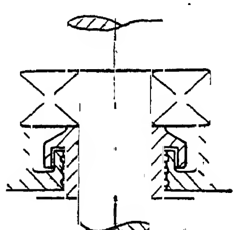


Fig. 53.—Method of retaining lubricant on a vertical shaft.

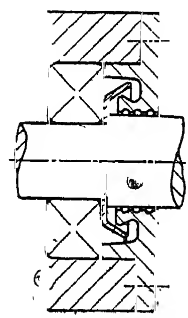


Fig. 54.—Method of retaining oil on a horizontal shaft.

rubbing surfaces of the cage and also for protecting the highly finished working parts of the bearings.

While oil is undoubtedly the more efficient lubricant, grease combines effective lubrication with permanent coating properties, and therefore affords maximum protection for the bearings. Oil, on the other hand, is liable to drain away and leave the bearing parts dry and exposed to the danger of rust caused by condensation if the machine is idle for prolonged periods. Grease has the further advantages that it is easier to retain in the bearing housing and that it adds to the effectiveness of the closure, and therefore assists in excluding dirt and moisture. Wherever practicable, therefore, grease lubrication is recommended.

Grease.—A suitable grease should have a mineral base (lime or soda), but should contain no free mineral acid and be free from alkali or foreign matter. No filling agent should be employed, for the presence of such substances as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graphite, talcum, etc., although in an extremely fine state of subdivision, will give rise to lapping of the bearing parts and so cause wear. Even " colloidal graphite " is not considered satisfactory in grease, as it is liable to cause separation. Stability is of the utmost importance, and the grease should show no tendency to gum, thin out, or separate into its constituents on standing or in service.

For normal conditions, a good-quality lime-soap grease of medium consistency, and having a melting-point of approximately 200° F., is recommended, and such a lubricant should withstand a continuous running temperature of 100°–110° F.

For conditions involving high speed and/or high temperature, a soda-soap grease should be used. These lubricants usually have a melting-point of 300°–350° F. with a proportionately higher consistency, and care should be exercised in their selection to ensure the best results. The softer greases of this type will be found suitable for working temperatures up to 150° F., whilst those of higher consistency, which are usually termed high-melting-point greases, will operate satisfactorily at temperatures up to 220° F.

The limiting speeds for which the different types of grease are suitable vary according to the size and type of the bearing, but Fig. 42, which gives the approximate maximum speeds of standard ball and roller journal bearings when lubricated with lime-soap or soda-soap grease, will serve as a guide. In general the permissible working temperature will be limited by the degree of mechanical agitation to which the grease is subjected.

Before the bearings are set to work they should be thoroughly charged with grease, this being worked into the moving parts to ensure an efficient coating of their surfaces. The housing also should be lightly packed with grease, for it is important that a reserve supply of lubricant should be maintained in actual contact with the sides of the bearing in order to promote satisfactory and continuous lubrication. In this connection the depth of recesses in the end covers should be made approximately one-third to one-half of the bearing width.

Overfilling or cramming should be avoided, for excessive greasing may cause overheating due to churning, and if two bearings are mounted in the same housing they should be spaced apart by distance-pieces between their races, unless the speed is relatively slow. Also clamping nuts, and in fact all rotating parts in close proximity to the bearings, should be smooth on their outer surfaces and as small as practicable, otherwise they may cause churning of the grease or act as throwers and starve the bearing of lubricant.

If correctly applied, one charge of grease will last for a considerable period, this varying with the working conditions, but in cases where the speed is not high and the temperature normal, it is usually necessary to inject only a small quantity of grease every six to twelve months to make up for shrinkage and to disturb the lubricant in the housing.

Oil.—A good-quality mineral oil is recommended. Animal and vegetable oils should be avoided, as they tend to become rancid and to develop free acid with detrimental results to the bearings.

Oil lubrication should be applied in the following cases :

(1) For light machines where the resistance must be reduced to an absolute minimum.

(2) Where the bearings are completely enclosed in casings containing other parts for which oil lubrication is necessary, an example being gearboxes. Another case is when anti-friction bearings are required to operate with plain bearings.

(3) Where the speed is unusually high. In such cases a good-quality mineral oil of light to medium viscosity should be used.

(4) For temperature conditions in excess of 220° F. Here a steam-cylinder oil is recommended.

In no case should a bearing be run completely flooded in oil, as this will cause churning and result in considerable temperature rise.

On horizontal shafts, unless the speed is extremely high, the oil level should be maintained at a height approximately half-way up the lowest ball or roller in the bearing.

In applications such as gearboxes where the bearings are enclosed an oil mist is usually present or can be easily arranged for, and unless the bearings are seriously masked this will generally provide sufficient lubrication.

For very high speeds or vertical shafts, a circulation system providing a continuous drip feed should be arranged, drains being provided at the bottom of the housings to prevent flooding.

FITTING

Handling and Fitting of Bearings.—Absolute cleanliness is essential, and for this reason a bearing should not be removed from its wrappings until the last possible moment.

All parts to which the bearings are to be fitted should be thoroughly clean and all chips and machining swarf removed. Tapped holes and castings which have not been carefully cleaned are a frequent source of foreign matter in bearings.

A race which is to be an interference fit on its seating should not be subjected to direct blows from a hammer. It should be carefully fitted in position by taps from a mallet, or a hardwood drift with an ordinary hammer can be employed. In either case the blows should be distributed around the circumference to ensure the race is not canted on its seating during the process.

In some cases it may be possible to tap the race on to its seating by blows transmitted through a tube of suitable diameter in direct contact with the race concerned.

The best method of fitting races which are to be an interference fit is to press them on to their seatings by means of an arbour press, but this is not always available.

Bearings are sometimes heated in oil and shrunk on to their seatings, but where this process is employed the temperature of the oil should not exceed 100°–120° C., and special attention should be given to the matter of cleanliness.

In no case should a race be forced into position by means of pressure or blows on its companion race. The pressure should be applied to the particular race that is being mounted, as otherwise considerable damage may be done to the tracks and rolling elements.

When assembling roller journal bearings with detachable races, it is often convenient to mount the races on the shaft and in the housing separately before assembly of the machine. In such cases during the final assembly special care must be taken to ensure the machine parts are not tilted and that their weights are adequately supported, as otherwise the rollers are liable to score the tracks when sliding into position.

Where thrust bearings are involved, particularly large sizes involving appreciable weight of parts, it is an advantage if assembly can be carried out with the shaft axes vertical. This enables the race tracks and cage and balls to be maintained concentric without difficulty. If assembled with the shaft horizontal, the cage and balls may drop and become eccentric to the tracks so that they would be nipped on application of the working load.

As soon after fitting as possible bearings should be charged with lubricant and the housing end covers fixed in position.

Dismantling.—It is sometimes necessary to dismantle a machine at intervals for inspection and overhaul, and in such cases ease in dismantling becomes an important feature. Special attention must be given to the design of the machine components and also to the selection of the types of bearings employed, as the latter can greatly facilitate dismantling as well as assembly.

It must be remembered that a machine that is easily assembled is not necessarily as easily dismantled. Provision must be made for withdrawing the races from their seatings and, in the same way as when mounting, the pressure should be applied to the individual race concerned and not to its companion race, as otherwise the parts may be so damaged as to render them unfit for further service.

In the case of single-row self-aligning bearings with swivelling end covers, it will be seen from Fig. 55 that flanged distance-pieces must be fitted between the shaft shoulders and the bearing inner races if the latter are to be withdrawn without causing severe damage to the bearing. This principle is frequently employed in connection with other types of journal bearings and has the advantage that the withdrawing pressure is transmitted to the solid portion of the race, and is therefore not liable to damage any lips.

Where an inner race has to be pressed directly against a shaft shoulder, means of dismounting can be arranged by providing slots milled in the shaft shoulder (as Fig. 56) to allow a suitable tool to be inserted behind the race.

Outer races pressed into shouldered housings (as shown in Fig. 57) can be removed readily if two holes are provided through the shoulder, parallel with the bearing axis and diametrically opposite one another. Suitable rods inserted into the holes enable the race to be tapped out of the housing. Alternatively if tapped holes are provided bolts can be screwed in and the race pressed out of the housing.

Figs. 58 and 59 show two designs in which particular attention has been given to ease of assembly and dismantling. The former shows a modern traction-motor bearing arrangement making use of cylindrical roller bearings having special lip arrangements on their races. The bearing at the commutator end is provided with lips on both its races, so that it will locate the shaft endways. It will be seen that the armature can be easily removed from the carcase for cleaning, as the end shields can be withdrawn complete with outer races, cage, and rollers, leaving the inner races in position on the shaft.

Fig. 59 shows an axle-box arrangement that has proved very successful, and here again cylindrical roller bearings with special lip arrangements on their races are employed. It will be seen that each bearing locates and will take end thrust in one direction, and also that when the axle clamping plate is removed the axle box can be withdrawn complete with outer races, cages, and rollers, leaving the inner races in position on the axle.

In both cases the shafts can be threaded and the races held endways by clamping nuts if these are preferred.

LOAD CAPACITY

The mathematical theories of Hertz, and the later investigations of Stribeck, Goodman, and others, have formed the basis of research carried out by bearing manufacturers in connection with load-carrying capacity.

The calculated capacity of a bearing depends on the size and number of balls or rollers fitted, but, when deciding on these, due attention must be given to the proportions of the races and cages, having in mind the fact that the external dimensions of standard anti-friction bearings are fixed by international agreement. At the same time different makers allow different proportions for these components, and there may be considerable variation in the internal construction of bearings of the same size and type.

Although it is possible to calculate the actual stress intensity set up in the working parts of a bearing under a given static load, the load capacities published by different makers vary considerably, even in cases where the numbers and size of the rolling elements are the same. This is due to the different factors of safety incorporated in the formulæ, but the differences tend to balance out when the load capacities are applied to actual working conditions.

It cannot be overstressed that it is impossible to compile tables giving safe loads for anti-friction bearings that will meet all conditions of service. Correct bearing selection can be made only after consideration has been given to magnitude and nature of the load, also the speed, in relation to the operating conditions of the particular application concerned.

While in many applications it may be possible to calculate the nominal bearing loads accurately, these may bear little relation to the shocks and induced stresses that occur under running conditions. For example, it is definitely established that a bearing subjected to a live load, such as that from gear tooth pressure, and mounted in a relatively light housing is operating under considerably easier conditions, other things being equal, than an identical bearing carrying a dead-weight load of the same magnitude and mounted in a cast-iron bed plate of solid proportions. In the latter case, due to the heavy masses present, vibrations have to be absorbed almost entirely by the races and rolling elements, and if the stress at any time is sufficient to cause permanent indentation of the tracks, this will quickly lead to complete failure of the bearing.

The figures given in load tables, therefore, should not be rigidly adhered to, but should be regarded primarily as a means for comparing the relative strengths

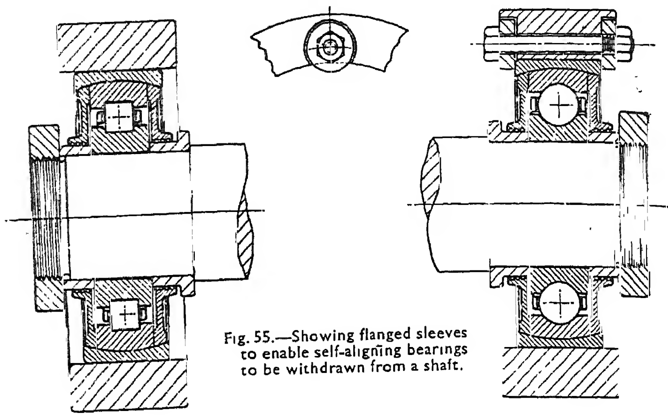


Fig. 55.—Showing flanged sleeves to enable self-aligning bearings to be withdrawn from a shaft.

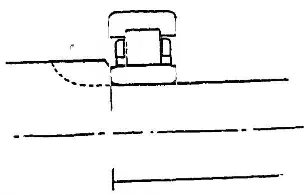


Fig. 56.—Slots milled in a shaft shoulder to enable an inner race to be withdrawn.

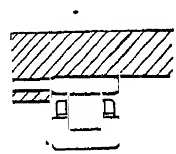


Fig. 57.—Holes drilled through a solid housing shoulder to enable an outer race to be pushed off.

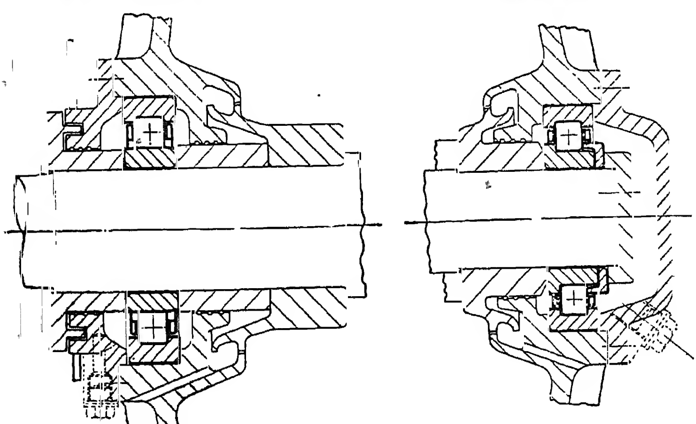


Fig. 58.—A modern traction-motor bearing arrangement designed for easy dismantling.

of bearings of the same make and the selection based on previous experience of bearings operating under similar conditions. At the same time close attention must be given to the various factors of safety advised by the manufacturers in connection with their own products.

Ball Journal Bearings under Thrust.—As a guide, the amount of thrust load with which a single-row rigid ball journal bearing will deal can be taken as approximately one-third of the journal rating, if the thrust is due to dead weight, or two-thirds of the journal rating if the thrust is of a flexible nature, such as that due to hydraulic or air pressure or gear tooth pressure. If the bearing

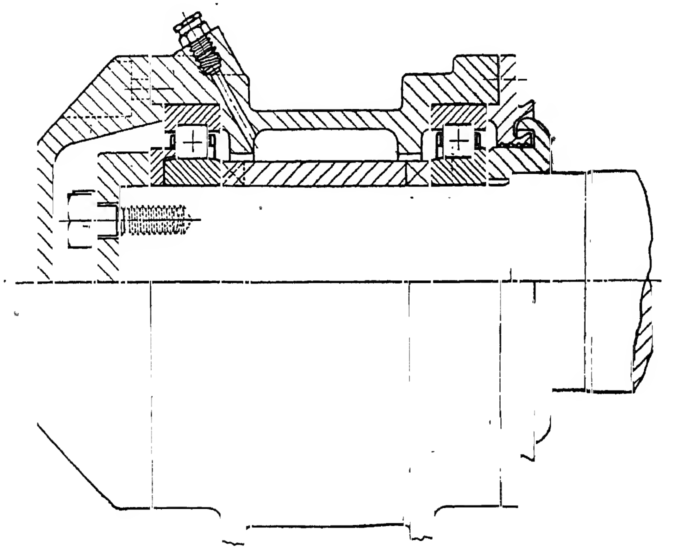


Fig. 59.—An axle-box arrangement designed for easy dismantling.

is also required to deal with journal load, this must first be subtracted from the journal rating before the permissible thrust load can be estimated. The rated journal capacity should not be less than:

Factored journal load + 3 × Weight thrust.

or

Factored journal load + 1·5 × Live thrust.

Load-capacity Formulæ.—To enable users to make their own comparison of the relative strengths of bearings, where the necessary information is available, formulæ are given below and the following notation has been used:

L = The calculated capacity in pounds.
d = The diameter of the balls or rollers in inches.
l = The length of the rollers in inches.
n = The number of balls or rollers in the bearing.
D = The diameter of the ball path in inches.
N = The speed of the bearing in R.P.M.
K = A constant for Stribeck's formula.
C = A constant for Goodman's formula.
k = A constant for Goodman's formula.
Z = A constant for the roller journal bearing formula.

Stribeck's Formula (Ball Journal Bearings).—Stribeck estimated that the maximum load coming on one ball in a loaded ball journal bearing to be Bearing load × $5/n$, and this has since been proved by laboratory tests to be substantially correct. From this he developed the following formula giving the maximum static load for a ball journal bearing:

$$L = \frac{K\,n\,d^2}{5}$$

The value of the constant "K" depends on the design and finish of the ball

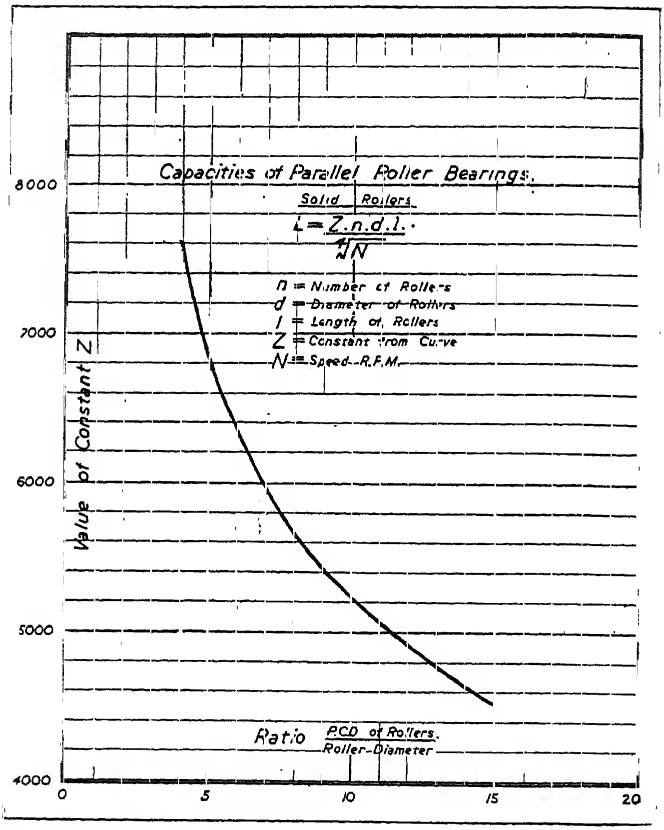


Fig. 60.—Graph for use in connection with formula for capacities of cylindrical roller journal bearings. (See p. 425.)

tracks, and values have subsequently been published which make allowance for reduction in bearing capacity at various speeds. See table below:

N	1	10	150	300	500	1000	1200	1500	2000	2500	3000	4000	5000	10000
K	3100	2325	1850	1550	1330	1000	950	875	775	675	620	550	500	325

Goodman's Formula (Ball Journal and Thrust Bearings).—This is as follows:

$$L = \frac{C\,n\,d^3}{N\,D + k\,d}$$

Type of Bearing		C	*k*
Journal	grooved tracks	2,500,000	2000
Thrust	flat tracks	500,000	200
Thrust	grooved tracks	1,250,000	200

It will be found that the capacities of ball bearings obtained from the above formulæ are in most cases rather lower than the figures published by manufacturers, particularly at the higher speeds. This is understandable, having in mind the considerable improvements made in bearing design and materials used, and also the consistently higher standards of excellence obtained by modern manufacturing methods.

Formula for Parallel-roller Journal Bearings (Solid Rollers).—The following formula gives figures which compare favourably with the capacities published by some manufacturers:

$$L = \frac{Z\,n\,d\,l}{\sqrt[4]{N}}$$

Values for "Z" must be obtained from the graph in Fig. 60, and depend on the ratio, Pitch circle diameter : Roller diameter for the particular bearing under consideration.

TABLE No. 1

MEDIUM TYPE—SINGLE-THRUST BEARINGS

Dimensions (in.)			*B.S.I.*	*Hoffmann*	*R. & M.*	*SKF.*	*Fischer*
Bore	*O.D.*	*Width*					
$\frac{3}{4}$	$1\frac{9}{16}$	$\frac{23}{32}$	SFM $\frac{3}{4}$	MW $\frac{3}{4}$	MT $\frac{3}{4}$	T 6	T 6
$\frac{7}{8}$	$1\frac{13}{16}$	$\frac{3}{4}$	SFM $\frac{7}{8}$	MW $\frac{7}{8}$	MT $\frac{7}{8}$	T 7	T 7
1	2	$\frac{13}{16}$	SFM 1	MW 1	MT 1	T 8	T 8
$1\frac{1}{8}$	$2\frac{1}{4}$	$\frac{7}{8}$	SFM $1\frac{1}{8}$	MW $1\frac{1}{8}$	MT $1\frac{1}{8}$	T 9	T 9
$1\frac{1}{4}$	$2\frac{1}{2}$	1	SFM $1\frac{1}{4}$	MW $1\frac{1}{4}$	MT $1\frac{1}{4}$	T 10	T 10
$1\frac{1}{2}$	$2\frac{7}{8}$	$1\frac{1}{8}$	SFM $1\frac{1}{2}$	MW $1\frac{1}{2}$	MT $1\frac{1}{2}$	T 12	T 12
$1\frac{3}{4}$	$3\frac{5}{16}$	$1\frac{1}{4}$	SFM $1\frac{3}{4}$	MW $1\frac{3}{4}$	MT $1\frac{3}{4}$	T 14	T 14
2	$3\frac{11}{16}$	$1\frac{3}{8}$	SFM 2	MW 2	MT 2	T 16	T 16
$2\frac{1}{4}$	$4\frac{1}{4}$	$1\frac{11}{16}$	SFM $2\frac{1}{4}$	MW $2\frac{1}{4}$	MT $2\frac{1}{4}$	T 18	T 18
$2\frac{1}{2}$	$4\frac{3}{4}$	2	SFM $2\frac{1}{2}$	MW $2\frac{1}{2}$	MT $2\frac{1}{2}$	T 20	T 20
$2\frac{3}{4}$	5	2	SFM $2\frac{3}{4}$	MW $2\frac{3}{4}$	MT $2\frac{3}{4}$	T 22	T 22
3	$5\frac{5}{8}$	$2\frac{1}{4}$	SFM 3	MW 3	MT 3	T 24	T 24
$3\frac{1}{2}$	$6\frac{7}{16}$	$2\frac{1}{2}$	SFM $3\frac{1}{2}$	MW $3\frac{1}{2}$	MT $3\frac{1}{2}$	T 28	T 28
4	$7\frac{1}{4}$	$2\frac{13}{16}$	SFM 4	MW 4	MT 4E	T 32	T 32
$4\frac{1}{2}$	$8\frac{1}{4}$	$3\frac{3}{8}$	SFM $4\frac{1}{2}$	MW $4\frac{1}{2}$	MT $4\frac{1}{2}$E	T 36	T 36
5	$9\frac{1}{2}$	4	SFM 5	MW 5	MT 5E	T 40	T 40
$5\frac{1}{2}$	$10\frac{3}{8}$	$4\frac{1}{4}$	SFM $5\frac{1}{2}$	MW $5\frac{1}{2}$	MT $5\frac{1}{2}$E	T 44	T 44
6	$11\frac{1}{8}$	$4\frac{1}{2}$	SFM 6	MW 6	MT 6E	T 48	T 48

TABLE No. 2

LIGHT TYPE—ENGLISH JOURNAL BEARINGS

Dimensions (in.)			Single-row Rigid Ball Journal Bearings					Double-row Self-aligning Ball Journal Bearings					Roller Journal Bearings				
Bore	O.D.	Width	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer
1/2	1 5/16	3/8	BRL 1/2	LS 5	LJ 1/2	RLS 4	LS 5	BAL 1/2	ULS 5	NLJ 1/2	RL 4	RL 4	RRL 1/2	RLS 5	LRJ 1/2	—	—
5/8	1 9/16	7/16	BRL 5/8	LS 7	LJ 5/8	RLS 5	LS 7	BAL 5/8	ULS 7	NLJ 5/8	RL 5	RL 5	RRL 5/8	RLS 7	LRJ 5/8	—	—
3/4	1 7/8	9/16	BRL 3/4	LS 8	LJ 3/4	RLS 6	LS 8	BAL 3/4	ULS 8	NLJ 3/4	RL 6	RL 6	RRL 3/4	RLS 8	LRJ 3/4	CRL 6	—
7/8	2	9/16	BRL 7/8	LS 9	LJ 7/8	RLS 7	LS 9	BAL 7/8	ULS 9	NLJ 7/8	RL 7	RL 7	RRL 7/8	RLS 9	LRJ 7/8	CRL 7	—
1	2 1/4	5/8	BRL 1	LS 10	LJ 1	RLS 8	LS 10	BAL 1	ULS 10	NLJ 1	RL 8	RL 8	RRL 1	RLS 10	LRJ 1	CRL 8	RLS 10
1 1/8	2 1/2	5/8	BRL 1 1/8	LS 11	LJ 1 1/8	RLS 9	LS 11	BAL 1 1/8	ULS 11	NLJ 1 1/8	RL 9	RL 9	RRL 1 1/8	RLS 11	LRJ 1 1/8	CRL 9	RLS 11
1 1/4	2 3/4	11/16	BRL 1 1/4	LS 12	LJ 1 1/4	RLS 10	LS 12	BAL 1 1/4	ULS 12	NLJ 1 1/4	RL 10	RL 10	RRL 1 1/4	RLS 12	LRJ 1 1/4	CRL 10	RLS 12
1 3/8	3	11/16	BRL 1 3/8	LS 12 1/2	LJ 1 3/8	RLS 11	LS 12 1/2	BAL 1 3/8	ULS 12 1/2	NLJ 1 3/8	RL 11	RL 11	RRL 1 3/8	RLS 12 1/2	LRJ 1 3/8	CRL 11	RLS 12 1/2
1 1/2	3 1/4	3/4	BRL 1 1/2	LS 13	LJ 1 1/2	RLS 12	LS 13	BAL 1 1/2	ULS 13	NLJ 1 1/2	RL 12	RL 12	RRL 1 1/2	RLS 13	LRJ 1 1/2	CRL 12	RLS 13
1 5/8	3 1/2	3/4	BRL 1 5/8	LS 13 1/2	LJ 1 5/8	RLS 13	LS 13 1/2	BAL 1 5/8	ULS 13 1/2	NLJ 1 5/8	RL 13	RL 13	RRL 1 5/8	RLS 13 1/2	LRJ 1 5/8	CRL 13	RLS 13 1/2
1 3/4	3 3/4	13/16	BRL 1 3/4	LS 14	LJ 1 3/4	RLS 14	LS 14	BAL 1 3/4	ULS 14	NLJ 1 3/4	RL 14	RL 14	RRL 1 3/4	RLS 14	LRJ 1 3/4	CRL 14	RLS 14
1 7/8	4	13/16	BRL 1 7/8	LS 14 1/2	LJ 1 7/8	RLS 15	LS 14 1/2	BAL 1 7/8	ULS 14 1/2	NLJ 1 7/8	RL 15	RL 15	RRL 1 7/8	RLS 14 1/2	LRJ 1 7/8	CRL 15	RLS 14 1/2
2	4	13/16	BRL 2	LS 15	LJ 2	RLS 16	LS 15	BAL 2	ULS 15	NLJ 2	RL 16	RL 16	RRL 2	RLS 15	LRJ 2	CRL 16	RLS 15
2 1/4	4 1/2	7/8	BRL 2 1/4	LS 16	LJ 2 1/4	RLS 18	LS 16	BAL 2 1/4	ULS 16	NLJ 2 1/4	RL 18	RL 18	RRL 2 1/4	RLS 16	LRJ 2 1/4	CRL 18	RLS 16
2 1/2	5	15/16	BRL 2 1/2	LS 17	LJ 2 1/2	RLS 20	LS 17	BAL 2 1/2	ULS 17	NLJ 2 1/2	RL 20	RL 20	RRL 2 1/2	RLS 17	LRJ 2 1/2	CRL 20	RLS 17
2 3/4	5 1/4	15/16	BRL 2 3/4	LS 18	LJ 2 3/4	RLS 22	LS 18	BAL 2 3/4	ULS 18	NLJ 2 3/4	RL 22	RL 22	RRL 2 3/4	RLS 18	LRJ 2 3/4	CRL 22	RLS 18
3	5 3/4	1 1/16	BRL 3	LS 19	LJ 3	RLS 24	LS 19	BAL 3	ULS 19	NLJ 3	RL 24	RL 24	RRL 3	RLS 19	LRJ 3	CRL 24	RLS 19
3 1/4	6	1 1/16	BRL 3 1/4	LS 19 1/2	LJ 3 1/4	RLS 26	LS 19 1/2	BAL 3 1/4	ULS 19 1/2	NLJ 3 1/4	RL 26	RL 26	RRL 3 1/4	RLS 19 1/2	LRJ 3 1/4	CRL 26	RLS 19 1/2
3 1/2	6 1/2	1 1/8	BRL 3 1/2	LS 20	LJ 3 1/2	RLS 28	LS 20	BAL 3 1/2	ULS 20	NLJ 3 1/2	RL 28	RL 28	RRL 3 1/2	RLS 20	LRJ 3 1/2	CRL 28	RLS 20
3 3/4	6 3/4	1 1/8	BRL 3 3/4	LS 20 1/2	LJ 3 3/4	RLS 30	LS 20 1/2	BAL 3 3/4	ULS 20 1/2	NLJ 3 3/4	RL 30	RL 30	RRL 3 3/4	RLS 20 1/2	LRJ 3 3/4	CRL 30	RLS 20 1/2
4	7 1/4	1 1/4	BRL 4	LS 21	LJ 4E	RLS 32	LS 21	BAL 4	ULS 21	NLJ 4E	RL 32	RL 32	RRL 4	RLS 21	LRJ 4E	CRL 32	RLS 21
4 1/4	7 1/2	1 1/4	BRL 4 1/4	LS 21 1/2	LJ 4 1/4E	RLS 34	LS 21 1/2	BAL 4 1/4	ULS 21 1/2	NLJ 4 1/4E	RL 34	RL 34	RRL 4 1/4	RLS 21 1/2	LRJ 4 1/4E	CRL 34	RLS 21 1/2
4 1/2	8	1 5/16	BRL 4 1/2	LS 22	LJ 4 1/2E	RLS 36	LS 22	BAL 4 1/2	ULS 22	NLJ 4 1/2E	RL 36	RL 36	RRL 4 1/2	RLS 22	LRJ 4 1/2E	CRL 36	RLS 22
4 3/4	8 1/4	1 5/16	BRL 4 3/4	LS 22 1/2	LJ 4 3/4E	RLS 38	LS 22 1/2	BAL 4 3/4	ULS 22 1/2	NLJ 4 3/4E	RL 38	RL 38	RRL 4 3/4	RLS 22 1/2	LRJ 4 3/4E	CRL 38	RLS 22 1/2
5	9	1 3/8	BRL 5	LS 23	LJ 5E	RLS 40	LS 23	BAL 5	ULS 23	NLJ 5E	RL 40	RL 40	RRL 5	RLS 23	LRJ 5E	CRL 40	RLS 23
5 1/2	9 1/2	1 3/8	BRL 5 1/2	LS 23 1/2	LJ 5 1/2E	RLS 44	LS 23 1/2	BAL 5 1/2	ULS 23 1/2	NLJ 5 1/2E	RL 44	RL 44	RRL 5 1/2	RLS 23 1/2	LRJ 5 1/2E	CRL 44	RLS 23 1/2
6	10 1/2	1 9/16	BRL 6	LS 24	LJ 6E	RLS 48	LS 24	BAL 6	ULS 24	NLJ 6E	RL 48	RL 48	RRL 6	RLS 24	LRJ 6E	CRL 48	RLS 24

TABLE No. 3

MEDIUM TYPE—ENGLISH JOURNAL BEARINGS

Dimensions (in.)			Single-row Rigid Ball Journal Bearings					Double-row Self-aligning Ball Journal Bearings					Roller Journal Bearings				
Bore	O.D.	Width	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer
1/4	1 5/16	9/16	BRM 1/4	MS 1	MJ 1/4	—	MS 1	BAM 1/4	UMS 1	NMJ 1/4	—	—	RRM 1/4	RMS 1	MRJ 1/4	—	—
3/8	1 1/2	9/16	BRM 3/8	MS 3	MJ 3/8	—	MS 3	BAM 3/8	UMS 3	NMJ 3/8	RM 3	RM 3	RRM 3/8	RMS 3	MRJ 3/8	—	—
1/2	1 5/8	5/8	BRM 1/2	MS 5	MJ 1/2	RMS 4	MS 5	BAM 1/2	UMS 5	NMJ 1/2	RM 4	RM 4	RRM 1/2	RMS 5	MRJ 1/2	—	—
5/8	1 13/16	5/8	BRM 5/8	MS 7	MJ 5/8	RMS 5	MS 7	BAM 5/8	UMS 7	NMJ 5/8	RM 5	RM 5	RRM 5/8	RMS 7	MRJ 5/8	—	RMS 7
3/4	2	11/16	BRM 3/4	MS 8	MJ 3/4	RMS 6	MS 8	BAM 3/4	UMS 8	NMJ 3/4	RM 6	RM 6	RRM 3/4	RMS 8	MRJ 3/4	—	RMS 8
7/8	2 1/4	11/16	BRM 7/8	MS 9	MJ 7/8	RMS 7	MS 9	BAM 7/8	UMS 9	NMJ 7/8	RM 7	RM 7	RRM 7/8	RMS 9	MRJ 7/8	CRM 7	RMS 9
1	2 1/2	3/4	BRM 1	MS 10	MJ 1	RMS 8	MS 10	BAM 1	UMS 10	NMJ 1	RM 8	RM 8	RRM 1	RMS 10	MRJ 1	CRM 8	RMS 10
1 1/8	2 13/16	13/16	BRM 1 1/8	MS 11	MJ 1 1/8	RMS 9	MS 11	BAM 1 1/8	UMS 11	NMJ 1 1/8	RM 9	RM 9	RRM 1 1/8	RMS 11	MRJ 1 1/8	CRM 9	RMS 11
1 1/4	3 1/8	7/8	BRM 1 1/4	MS 12	MJ 1 1/4	RMS 10	MS 12	BEM 1 1/4	UMS 12	NMJ 1 1/4	RM 10	RM 10	RRM 1 1/4	RMS 12	MRJ 1 1/4	CRM 10	RMS 12
1 3/8	3 1/2	7/8	BRM 1 3/8	MS 12 1/2	MJ 1 3/8	RMS 11	MS 12 1/2	BAM 1 3/8	UMS 12 1/2	NMJ 1 3/8	RM 11	RM 11	RRM 1 3/8	RMS 12 1/2	MRJ 1 3/8	CRM 11	RMS 12 1/2
1 1/2	3 3/4	15/16	BRM 1 1/2	MS 13	MJ 1 1/2	RMS 12	MS 13	BAM 1 1/2	UMS 13	NMJ 1 1/2	RM 12	RM 12	RRM 1 1/2	RMS 13	MRJ 1 1/2	CRM 12	RMS 13
1 5/8	4	15/16	BRM 1 5/8	MS 13 1/2	MJ 1 5/8	RMS 13	MS 13 1/2	BAM 1 5/8	UMS 13 1/2	NMJ 1 5/8	RM 13	RM 13	RRM 1 5/8	RMS 13 1/2	MRJ 1 5/8	CRM 13	RMS 13 1/2
1 3/4	4 1/4	1 1/16	BRM 1 3/4	MS14	MJ 1 3/4	RMS 14	MS 14	BAM 1 3/4	UMS 14	NMJ 1 3/4	RM 14	RM 14	RRM 1 3/4	RMS 14	MRJ 1 3/4	CRM 14	RMS 14
1 7/8	4 1/2	1 1/16	BRM 1 7/8	MS 14 1/2	MJ 1 7/8	RMS 15	MS 14 1/2	BAM 1 7/8	UMS 14 1/2	NMJ 1 7/8	RM 15	RM 15	RRM 1 7/8	RMS 14 1/2	MRJ 1 7/8	CRM 15	RMS 14 1/2
2	4 1/2	1 1/16	BRM 2	MS 15	MJ 2	RMS 16	MS 15	BAM 2	UMS 15	NMJ 2	RM 16	RM 16	RRM 2	RMS 15	MRJ 2	CRM 16	RMS 15
2 1/4	5	1 1/4	BRM 2 1/4	MS 16	MJ 2 1/4	RMS 18	MS 16	BAM 2 1/4	UMS 16	NMJ 2 1/4	RM 18	RM 18	RRM 2 1/4	RMS 16	MRJ 2 1/4	CRM 18	RMS 16
2 1/2	5 1/2	1 1/4	BRM 2 1/2	MS 17	MJ 2 1/2	RMS 20	MS 17	BAM 2 1/2	UMS 17	NMJ 2 1/2	RM 20	RM 20	RRM 2 1/2	RMS 17	MRJ 2 1/2	CRM 20	RMS 17
2 3/4	6 1/4	1 3/8	BRM 2 3/4	MS 18	MJ 2 3/4	RMS 22	MS 18	BAM 2 3/4	UMS 18	NMJ 2 3/4	RM 22	RM 22	RRM 2 3/4	RMS 18	MRJ 2 3/4	CRM 22	RMS 18
3	7	1 9/16	BRM 3	MS 19	MJ 3	RMS 24	MS 19	BAM 3	UMS 19	NMJ 3	RM 24	RM 24	RRM 3	RMS 19	MRJ 3	CRM 24	RMS 19
3 1/4	7 1/8	1 9/16	BRM 3 1/4	MS 19 1/4	MJ 3 1/4	RMS 26	MS 19 1/4	BAM 3 1/4	UMS 19 1/4	NMJ 3 1/4	RM 26	RM 26	RRM 3 1/4	RMS 19 1/4	MRJ 3 1/4	CRM 26	RMS 19 1/4
3 3/8	7 1/2	1 9/16	BRM 3 3/8	MS 19 3/4	MJ 3 3/8	RMS 27	MS 19 3/4	BAM 3 3/8	UMS 19 3/4	NMJ 3 3/8	RM 27	RM 27	RRM 3 3/8	RMS 19 3/4	MRJ 3 3/8	CRM 27	RMS 19 3/4
3 1/2	8 1/8	1 3/4	BRM 3 1/2	MS 20	MJ 3 1/2	RMS 28	MS 20	BAM 3 1/2	UMS 20	NMJ 3 1/2	RM 28	RM 28	RRM 3 1/2	RMS 20	MRJ 3 1/2	CRM 28	RMS 20
3 3/4	8 1/4	1 3/4	BRM 3 3/4	MS 20 1/2	MJ 3 3/4	RMS 30	MS 20 1/2	BAM 3 3/4	UMS 20 1/2	NMJ 3 3/4	RM 30	RM 30	RRM 3 3/4	RMS 20 1/2	MRJ 3 3/4	CRM 30	RMS 20 1/2
4	8 1/2	1 3/4	BRM 4	MS 21	MJ 4E	RMS 32	MS 21	BAM 4	UMS 21	NMJ 4E	RM 32	RM 32	RRM 4	RMS 21	MRJ 4E	CRM 32	RMS 21
4 1/4	8 3/4	1 3/4	BRM 4 1/4	MS 21 1/2	MJ 4 1/4E	RMS 34	MS 21 1/2	BAM 4 1/4	UMS 21 1/2	NMJ 4 1/4E	RM 34	RM 34	RRM 4 1/4	RMS 21 1/2	MRJ 4 1/4E	CRM 34	RMS 21 1/2
4 1/2	9 3/8	2	BRM 4 1/2	MS 22	MJ 4 1/2E	RMS 36	MS 22	BAM 4 1/2	UMS 22	NMJ 4 1/2E	RM 36	RM 36	RRM 4 1/2	RMS 22	MRJ 4 1/2E	CRM 36	RMS 22
4 3/4	10	2	BRM 4 3/4	MS 22 1/2	MJ 4 3/4E	RMS 38	MS 22 1/2	BAM 4 3/4	UMS 22 1/2	NMJ 4 3/4E	RM 38	RM 38	RRM 4 3/4	RMS 22 1/2	MRJ 4 3/4E	CRM 38	RMS 22 1/2
5	10	2	BRM 5	MS 23	MJ 5E	RMS 40	MS 23	BAM 5	UMS 23	NMJ 5E	RM 40	RM 40	RRM 5	RMS 23	MRJ 5E	CRM 40	RMS 23
5 1/2	11	2	BRM 5 1/2	MS 23 1/2	MJ 5 1/2E	—	MS 23 1/2	BAM 5 1/2	UMS 23 1/2	NMJ 5 1/2E	RM 44	RM 44	RRM 5 1/2	RMS 23 1/2	MRJ 5 1/2E	CRM 44	RMS 23 1/2
6	12	2 1/4	BRM 6	MS 24	MJ 6E	—	MS 24	BAM 6	UMS 24	NMJ 6E	RM 48	RM 48	RRM 6	RMS 24	MRJ 6E	CRM 48	RMS 24

TABLE NO. 4

LIGHT TYPE—METRIC JOURNAL BEARINGS

Dimensions (mm.)			Single-row Rigid Ball Journal Bearings					Double-row Self-aligning Ball Journal Bearings					Roller Journal Bearings				
Bore	O.D.	Width	B.S.I.	Hoff-mann	R. & M.	SKF.	Fischer	B.S.I.	Hoff-mann	R. & M.	SKF.	Fischer	B.S.I.	Hoff-mann	R. & M.	SKF.	Fischer
4	16	5	—	104	LJ 4	R 4	R 4	—	—	—	—	—	—	—	—	—	—
5	19	6	—	105	LJ 5	R 5	R 5	—	U 105	NLJ 5	13300	P 13300	—	—	—	—	—
6	19	6	—	106	LJ 6	R 5/6	R 5/6	—	U 106	NLJ 6	13301	P 13301	—	—	—	—	—
7	22	7	—	107	LJ 7	R 7	R 7	—	U 107	NLJ 7	13302	P 13302	—	—	—	—	—
8	22	7	—	108	LJ 8	R 7/8	R 7/8	—	U 108	NLJ 8	13303	P 13303	—	—	—	—	—
9	26	8	—	109	LJ 9	R 9	R 9	—	U 109	NLJ 9	13304	P 13304	—	—	—	—	—
10	30	9	BRL 010	110	LJ 10	6200	6200	BAL 010	U 110	NLJ 10	1200	P 200	RRL 010	R 110	LRJ 10	—	—
12	32	10	BRL 012	112	LJ 12	6201	6201	BAL 012	U 112	NLJ 12	1201	P 201	RRL 012	R 112	LRJ 12	—	—
15	35	11	BRL 015	115	LJ 15	6202	6202	BAL 015	U 115	NLJ 15	1202	P 202	RRL 015	R 115	LRJ 15	—	—
17	40	12	BRL 017	117	LJ 17	6203	6203	BAL 017	U 117	NLJ 17	1203	P 203	RRL 017	R 117	LRJ 17	NL 17	NL 17
20	47	14	BRL 020	120	LJ 20	6204	6204	BAL 020	U 120	NLJ 20	1204	P 204	RRL 020	R 120	LRJ 20	NL 20	NL 20
25	52	15	BRL 025	125	LJ 25	6205	6205	BAL 025	U 125	NLJ 25	1205	P 205	RRL 025	R 125	LRJ 25	NL 25	NL 25
30	62	16	BRL 030	130	LJ 30	6206	6206	BAL 030	U 130	NLJ 30	1206	P 206	RRL 030	R 130	LRJ 30	NL 30	NL 30
35	72	17	BRL 035	135	LJ 35	6207	6207	BAL 035	U 135	NLJ 35	1207	P 207	RRL 035	R 135	LRJ 35	NL 35	NL 35
40	80	18	BRL 040	140	LJ 40	6208	6208	BAL 040	U 140	NLJ 40	1208	P 208	RRL 040	R 140	LRJ 40	NL 40	NL 40
45	85	19	BRL 045	145	LJ 45	6209	6209	BAL 045	U 145	NLJ 45	1209	P 209	RRL 045	R 145	LRJ 45	NL 45	NL 45
50	90	20	BRL 050	150	LJ 50	6210	6210	BAL 050	U 150	NLJ 50	1210	P 210	RRL 050	R 150	LRJ 50	NL 50	NL 50
55	100	21	BRL 055	155	LJ 55	6211	6211	BAL 055	U 155	NLJ 55	1211	P 211	RRL 055	R 155	LRJ 55	NL 55	NL 55
60	110	22	BRL 060	160	LJ 60	6212	6212	BAL 060	U 160	NLJ 60	1212	P 212	RRL 060	R 160	LRJ 60	NL 60	NL 60
65	120	23	BRL 065	165	LJ 65	6213	6213	BAL 065	U 165	NLJ 65	1213	P 213	RRL 065	R 165	LRJ 65	NL 65	NL 65
70	125	24	BRL 070	170	LJ 70	6214	6214	BAL 070	U 170	NLJ 70	1214	P 214	RRL 070	R 170	LRJ 70	NL 70	NL 70
75	130	25	BRL 075	175	LJ 75	6215	6215	BAL 075	U 175	NLJ 75	1215	P 215	RRL 075	R 175	LRJ 75	NL 75	NL 75
80	140	26	BRL 080	180	LJ 80	6216	6216	BAL 080	U 180	NLJ 80	1216	P 216	RRL 080	R 180	LRJ 80	NL 80	NL 80
85	150	28	BRL 085	185	LJ 85	6217	6217	BAL 085	U 185	NLJ 85	1217	P 217	RRL 085	R 185	LRJ 85	NL 85	NL 85
90	160	30	BRL 090	190	LJ 90	6218	6218	BAL 090	U 190	NLJ 90	1218	P 218	RRL 090	R 190	LRJ 90	NL 90	NL 90
95	170	32	BRL 095	195	LJ 95	6219	6219	BAL 095	U 195	NLJ 95	1219	P 219	RRL 095	R 195	LRJ 95	NL 95	NL 95
100	180	34	BRL 100	200	LJ 100	6220	6220	BAL 100	U 200	NLJ 100	1220	P 220	RRL 100	R 200	LRJ 100	NL 100	NL 100
105	190	36	—	205	LJ 105	6221	6221	—	U 205	NLJ 105	1221	P 221	—	R 205	LRJ 105	NL 105	NL 105
110	200	38	BRL 110	210	LJ 110	6222	6222	BAL 110	U 210	NLJ 110	1222	P 222	RRL 110	R 210	LRJ 110	NL 110	NL 110
115	210	40	—	215	LJ 115	—	—	—	U 215	NLJ 115	—	—	—	R 215	—	—	—
120	215	42	—	220	LJ 120	—	—	—	U 220	NLJ 120	—	—	—	R 220	—	—	—

TABLE No. 5

MEDIUM TYPE—METRIC SIZES

Dimensions (mm.)			*Single-row Rigid Ball Journal Bearings*					*Double-row Self-aligning Ball Journal Bearings*					*Roller Journal Bearings*				
Bore	*O.D.*	*Width*	*B.S.I.*	*Hoff-mann*	*R. & M.*	*SKF.*	*Fischer*	*B.S.I.*	*Hoff-mann*	*R. & M.*	*SKF.*	*Fischer*	*B.S.I.*	*Hoff-mann*	*R. & M.*	*SKF.*	*Fischer*
10	35	11	BRM 010	310	MJ 10	6300	6300	BAM 010	U 310	NMJ 10	1300	P 300	RRM 010	R 310	MRJ 10	—	—
12	37	12	BRM 012	312	MJ 12	6301	6301	BAM 012	U 312	NMJ 12	1301	P 301	RRM 012	R 312	MRJ 12	—	—
15	42	13	BRM 015	315	MJ 15	6302	6302	BAM 015	U 315	NMJ 15	1302	P 302	RRM 015	R 315	MRJ 15	—	—
17	47	14	BRM 017	317	MJ 17	6303	6303	BAM 017	U 317	NMJ 17	1303	P 303	RRM 017	R 317	MRJ 17	—	—
20	52	15	BRM 020	320	MJ 20	6304	6304	BAM 020	U 320	NMJ 20	1304	P 304	RRM 020	R 320	MRJ 20	NM 20	NM 20
25	62	17	BRM 025	325	MJ 25	6305	6305	BAM 025	U 325	NMJ 25	1305	P 305	RRM 025	R 325	MRJ 25	NM 25	NM 25
30	72	19	BRM 030	330	MJ 30	6306	6306	BAM 030	U 330	NMJ 30	1306	P 306	RRM 030	R 330	MRJ 30	NM 30	NM 30
35	80	21	BRM 035	335	MJ 35	6307	6307	BAM 035	U 335	NMJ 35	1307	P 307	RRM 035	R 335	MRJ 35	NM 35	NM 35
40	90	23	BRM 040	340	MJ 40	6308	6308	BAM 040	U 340	NMJ 40	1308	P 308	RRM 040	R 340	MRJ 40	NM 40	NM 40
45	100	25	BRM 045	345	MJ 45	6309	6309	BAM 045	U 345	NMJ 45	1309	P 309	RRM 045	R 345	MRJ 45	NM 45	NM 45
50	110	27	BRM 050	350	MJ 50	6310	6310	BAM 050	U 350	NMJ 50	1310	P 310	RRM 050	R 350	MRJ 50	NM 50	NM 50
55	120	29	BRM 055	355	MJ 55	6311	6311	BAM 055	U 355	NMJ 55	1311	P 311	RRM 055	R 355	MRJ 55	NM 55	NM 55
60	130	31	BRM 060	360	MJ 60	6312	6312	BAM 060	U 360	NMJ 60	1312	P 312	RRM 060	R 360	MRJ 60	NM 60	NM 60
65	140	33	BRM 065	365	MJ 65	6313	6313	BAM 065	U 365	NMJ 65	1313	P 313	RRM 065	R 365	MRJ 65	NM 65	NM 65
70	150	35	BRM 070	370	MJ 70	6314	6314	BAM 070	U 370	NMJ 70	1314	P 314	RRM 070	R 370	MRJ 70	NM 70	NM 70
75	160	37	BRM 075	375	MJ 75	6315	6315	BAM 075	U 375	NMJ 75	1315	P 315	RRM 075	R 375	MRJ 75	NM 75	NM 75
80	170	39	BRM 080	380	MJ 80	6316	6316	BAM 080	U 380	NMJ 80	1316	P 316	RRM 080	R 380	MRJ 80	NM 80	NM 80
85	180	41	BRM 085	385	MJ 85	6317	6317	BAM 085	U 385	NMJ 85	1317	P 317	RRM 085	R 385	MRJ 85	NM 85	NM 85
90	190	43	BRM 090	390	MJ 90	6318	6318	BAM 090	U 390	NMJ 90	1318	P 318	RRM 090	R 390	MRJ 90	NM 90	NM 90
95	200	45	BRM 095	395	MJ 95	6319	6319	BAM 095	U 395	NMJ 95	1319	P 319	RRM 095	R 395	MRJ 95	NM 95	NM 95
100	215	47	BRM 100	400	MJ 100	6320	6320	BAM 100	U 400	NMJ 100	1320	P 320	RRM 100	R 400	MRJ 100	NM 100	NM 100
105	225	49	—	405	MJ 105	6321	6321	—	U 405	NMJ 105	1321	P 321	—	R 405	MRJ 105	NM 105	NM 105
110	240	50	BRM 110	410	MJ 110	6322	6322	BAM 110	U 410	NMJ 110	1322	P 322	RRM 110	R 410	MRJ 110	NM 110	NM 110
115	250	53	—	415	MJ 115	—	—	—	U 415	NMJ 115	—	—	—	R 415	—	—	—
120	260	55	BRM 120	420	MJ 120	6324	6324	BAM 120	U 420	NMJ 120	1324	—	RRM 120	R 420	—	NM 120	NM 120

Table No. 6

Heavy Type—Metric Sizes

Journal Bearings

Dimensions (mm.)			Single-row Rigid Ball Journal Bearings					Double-row Self-aligning Ball Journal Bearings					Roller Journal Bearings				
Bore	O.D.	Width	B.S.I.	Hoff-mann	R. & M.	SKF.	Fischer	B.S.I.	Hoff-mann	R. & M.	SKF.	Fischer	B.S.I.	Hoff-mann	R. & M.	SKF.	Fischer
17	62	17	BRH 017	517	HJ 17	6403	6403	BAH 017	U 517	NHJ 17	—	—	—	R 517	HRJ 17	—	—
20	72	19	BRH 020	520	HJ 20	6404	6404	BAH 020	U 520	NHJ 20	—	—	—	R 520	HRJ 20	—	—
25	80	21	BRH 025	525	HJ 25	6405	6405	BAH 025	U 525	NHJ 25	10405	P 405	—	R 525	HRJ 25	NS 25	NS 25
30	90	23	BRH 030	530	HJ 30	6406	6406	BAH 030	U 530	NHJ 30	10406	P 406	—	R 530	HRJ 30	NS 30	NS 30
35	100	25	BRH 035	535	HJ 35	6407	6407	BAH 035	U 535	NHJ 35	10407	P 407	—	R 535	HRJ 35	NS 35	NS 35
40	110	27	BRH 040	540	HJ 40	6408	6408	BAH 040	U 540	NHJ 40	10408	P 408	—	R 540	HRJ 40	NS 40	NS 40
45	120	29	BRH 045	545	HJ 45	6409	6409	BAH 045	U 545	NHJ 45	10409	P 409	—	R 545	HRJ 45	NS 45	NS 45
50	130	31	BRH 050	550	HJ 50	6410	6410	BAH 050	U 550	NHJ 50	10410	P 410	—	R 550	HRJ 50	NS 50	NS 50
55	140	33	BRH 055	555	HJ 55	6411	6411	BAH 055	U 555	NHJ 55	10411	P 411	—	R 555	HRJ 55	NS 55	NS 55
60	150	35	BRH 060	560	HJ 60	6412	6412	BAH 060	U 560	NHJ 60	10412	P 412	—	R 560	HRJ 60	NS 60	NS 60
65	160	37	BRH 065	565	HJ 65	6413	6413	BAH 065	U 565	NHJ 65	10413	P 413	—	R 565	HRJ 65	NS 65	NS 65
70	180	42	BRH 070	570	HJ 70	6414	6414	BAH 070	U 570	NHJ 70	10414	P 414	—	R 570	HRJ 70	NS 70	NS 70
75	190	45	BRH 075	575	HJ 75	6415	6415	BAH 075	U 575	NHJ 75	10415	P 415	—	R 575	HRJ 75	NS 75	NS 75
80	200	48	BRH 080	580	HJ 80	6416	6416	BAH 080	U 580	NHJ 80	10416	P 416	—	R 580	HRJ 80	NS 80	NS 80
85	210	52	BRH 085	585	HJ 85	6417	6417	BAH 085	U 585	NHJ 85	10417	P 417	—	R 585	HRJ 85	NS 85	NS 85
90	225	54	BRH 090	590	HJ 90	6418	—	BAH 090	U 590	NHJ 90	10418	—	—	R 590	HRJ 90	NS 90	NS 90
95	250	55	BRH 095	595	HJ 95	—	—	BAH 095	U 595	NHJ 95	—	—	—	R 595	HRJ 95	—	NS 95
100	265	60	BRH 100	600	HJ 100	—	—	BAH 100	U 600	NHJ 100	—	—	—	R 600	HRJ 100	—	NS 100

TABLE No. 7

SMALL TYPE—SINGLE-ROW RIGID BALL JOURNAL BEARINGS, ENGLISH DIMENSIONS

Dimensions (in.)			B.S.I.	Hoffmann		R. & M.		SKF.		Fischer
Bore	*O.D.*	*Width*		*With Cage*	*Without Cage*	*With Cage*	*Without Cage*	*With Cage*	*Without Cage*	*With Cage*
$\frac{1}{4}$	$\frac{3}{4}$	$\frac{7}{32}$	BRE $\frac{1}{4}$	S 1	S 1 B	KLNJ $\frac{1}{4}$	LNJ $\frac{1}{4}$	EE 2	EEP 2	S/EE 2
$\frac{3}{8}$	$\frac{7}{8}$	$\frac{7}{32}$	BRE $\frac{3}{8}$	S 3	S 3 B	KLNJ $\frac{3}{8}$	LNJ $\frac{3}{8}$	EE 3	EEP 3	S/EE 3
$\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{4}$	BRE $\frac{1}{2}$	S 5	S 5 B	KLNJ $\frac{1}{2}$	LNJ $\frac{1}{2}$	EE 4	EEP 4	S/EE 4
$\frac{5}{8}$	$1\frac{3}{8}$	$\frac{5}{16}$	BRE $\frac{5}{8}$	S 7	S 7 B	KLNJ $\frac{5}{8}$	LNJ $\frac{5}{8}$	EE 5	EEP 5	S/EE 5
$\frac{3}{4}$	$1\frac{5}{8}$	$\frac{9}{32}$	BRE $\frac{3}{4}$	S 8	S 8 B	KLNJ $\frac{3}{4}$	LNJ $\frac{3}{4}$	EE 6	EEP 6	S/EE 6
$\frac{7}{8}$	$1\frac{7}{8}$	$\frac{3}{8}$	BRE $\frac{7}{8}$	S 9	S 9 B	KLNJ $\frac{7}{8}$	LNJ $\frac{7}{8}$	EE 8	EEP 8	S/EE 8
1	2	$\frac{3}{8}$	BRE 1	S 10	S 10 B	KLNJ 1	LNJ 1	EE 9	EEP 9	S/EE 9
$1\frac{1}{8}$	$2\frac{1}{8}$	$\frac{3}{8}$	BRE $1\frac{1}{8}$	S 11	S 11 B	KLNJ $1\frac{1}{8}$	LNJ $1\frac{1}{8}$	EE 10	EEP 10	S/EE 10
$1\frac{1}{4}$	$2\frac{1}{4}$	$\frac{3}{8}$	BRE $1\frac{1}{4}$	S 12	S 12 B	KLNJ $1\frac{1}{4}$	LNJ $1\frac{1}{4}$	EE 11	EEP 11	—
$1\frac{3}{8}$	$2\frac{1}{2}$	$\frac{7}{16}$	BRE $1\frac{3}{8}$	S $12\frac{1}{2}$	S $12\frac{1}{2}$ B	KLNJ $1\frac{3}{8}$	LNJ $1\frac{3}{8}$	—	—	—
$1\frac{1}{2}$	$2\frac{5}{8}$	$\frac{7}{16}$	BRE $1\frac{1}{2}$	S 13	S 13 B	KLNJ $1\frac{1}{2}$	LNJ $1\frac{1}{2}$	—	—	—

B.S.S. 292 (1927)

The reader's attention is drawn to the following paragraphs in B.S.S. 292 (1927):

Para. 3 (*a*). Definition of Error due to Eccentricity.
Para. 4 (*a*). Definition of Error due to Wobble in Journal Bearings.
Para. 4 (*b*). Definition of Error due to Wobble in Thrust Bearings.
Table I. Permissible Error due to Eccentricity in Journal Bearings.
Table II. Permissible Error due to Eccentricity in Thrust Bearings.
Table III. Permissible Error due to Wobble in Journal Bearings.
Table IV. Permissible Error due to Wobble in Thrust Bearings.
Table V. Tolerances on Ball Journal Bearings and Parallel Roller Journal Bearings—Inch sizes.
Table VI. Tolerances on Ball Journal Bearings and Parallel Roller Journal Bearings—Metric sizes.
Table VII. Tolerances on Magneto-type Bearings.
Table VIII. Tolerances on Single Thrust Bearings with flat seatings—Inch sizes.
Table IX. Tolerances on Single Thrust Bearings with spherical seating rings—Inch sizes.
Table XII. Tolerances on Double Thrust Bearings with flat seatings—Inch sizes.
Table XIII. Tolerances on Double Thrust Bearings with sleeves—Inch sizes.

TABLE No. 8

MAGNETO TYPE—METRIC JOURNAL BEARINGS

Dimensions (*mm.*)			*B.S.I.*	*Hoffmann*	*R. & M.*	*SKF.*	*SKF.*	*Fischer*
Bore	*O.D.*	*Width*						
5	16	5	BML 005	A 5	M 5	E 5	—	E 5
6	21	7	BML 006	A 6	M 6	E 6	—	E 6
7	22	7	BML 007	A 7	M 7	E 7	EN 7	E 7
8	24	7	BML 008	A 8	M 8	E 8	EN 8	E 8
9	28	8	BML 009	A 9	M 9	E 9	—	E 9
10	28	8	BML 010	A 10	M 10	E 10	EN 10	E 10
11	32	7	BML 011	A 11	M 11	E 11	—	E 11
12	32	7	BML 012	A 12	M 12	E 12	—	E 12
13	30	7	BML 013	A 13	M 13	E 13	EN 13	E 13
14	35	8	BML 014	A 14	M 14	E 14	—	E 14
15	35	8	BML 015	A 15	M 15	E 15	EN 15	E 15
16	38	10	BML 016	A 16	M 16	E 16	—	E 16
17	44	11	BML 017	A 17	M 17	E 17	EN 17	E 17
18	40	9	BML 018	A 18	M 18	E 18	—	E 18
19	40	9	BML 019	A 19	M 19	E 19	—	E 19
20	47	12	—	A 20	M 20	E 20	—	E 20

Series E covers bearings made to limits + 0·000 to + 0·010 mm. on O.D.
Series EN covers bearings made to limits + 0·000 to − 0·10 mm. on O.D.
The former are intended for Continental use.

TABLE No. 9

HEAVY TYPE—SINGLE-THRUST BEARINGS

Dimensions (*in.*)			*B.S.I.*	*Hoffmann*	*R. & M.*	*SKF.*
Bore	*O.D.*	*Width*				
$\frac{1}{4}$	$\frac{15}{16}$	$\frac{17}{32}$	SFH $\frac{1}{4}$	HW $\frac{1}{4}$	HT $\frac{1}{4}$	VH 2
$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{5}{8}$	SFH $\frac{5}{16}$	HW $\frac{5}{16}$	HT $\frac{5}{16}$	VH $2\frac{1}{2}$
$\frac{3}{8}$	$1\frac{1}{8}$	$\frac{5}{8}$	SFH $\frac{3}{8}$	HW $\frac{3}{8}$	HT $\frac{3}{8}$	VH 3
$\frac{7}{16}$	$1\frac{5}{16}$	$\frac{23}{32}$	SFH $\frac{7}{16}$	HW $\frac{7}{16}$	HT $\frac{7}{16}$	VH $3\frac{1}{2}$
$\frac{1}{2}$	$1\frac{5}{16}$	$\frac{23}{32}$	SFH $\frac{1}{2}$	HW $\frac{1}{2}$	HT $\frac{1}{2}$	VH 4
$\frac{9}{16}$	$1\frac{9}{16}$	$\frac{3}{4}$	SFH $\frac{9}{16}$	HW $\frac{9}{16}$	HT $\frac{9}{16}$	VH $4\frac{1}{2}$
$\frac{5}{8}$	$1\frac{9}{16}$	$\frac{3}{4}$	SFH $\frac{5}{8}$	HW $\frac{5}{8}$	HT $\frac{5}{8}$	VH 5
$\frac{3}{4}$	$1\frac{13}{16}$	$\frac{7}{8}$	SFH $\frac{3}{4}$	HW $\frac{3}{4}$	HT $\frac{3}{4}$	VH 6
$\frac{7}{8}$	$2\frac{1}{16}$	1	SFH $\frac{7}{8}$	HW $\frac{7}{8}$	HT $\frac{7}{8}$	VH 7
1	$2\frac{7}{16}$	$1\frac{1}{8}$	SFH 1	HW 1	HT 1	VH 8
$1\frac{1}{8}$	$2\frac{11}{16}$	$1\frac{5}{16}$	SFH $1\frac{1}{8}$	HW $1\frac{1}{8}$	HT $1\frac{1}{8}$	VH 9
$1\frac{1}{4}$	3	$1\frac{1}{2}$	SFH $1\frac{1}{4}$	HW $1\frac{1}{4}$	HT $1\frac{1}{4}$	VH 10
$1\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{3}{4}$	SFH $1\frac{1}{2}$	HW $1\frac{1}{2}$	HT $1\frac{1}{2}$	VH 12
$1\frac{3}{4}$	4	2	SFH $1\frac{3}{4}$	HW $1\frac{3}{4}$	HT $1\frac{3}{4}$	VH 14
2	$4\frac{5}{8}$	$2\frac{1}{4}$	SFH 2	HW 2	HT 2	VH 16
$2\frac{1}{4}$	$5\frac{1}{4}$	$2\frac{1}{2}$	SFH $2\frac{1}{4}$	HW $2\frac{1}{4}$	HT $2\frac{1}{4}$	VH 18
$2\frac{1}{2}$	$5\frac{3}{4}$	$2\frac{3}{4}$	SFH $2\frac{1}{2}$	HW $2\frac{1}{2}$	HT $2\frac{1}{2}$	VH 20
$2\frac{3}{4}$	6	$2\frac{3}{4}$	SFH $2\frac{3}{4}$	HW $2\frac{3}{4}$	HT $2\frac{3}{4}$	VH 22
3	$6\frac{7}{8}$	$3\frac{3}{8}$	SFH 3	HW 3	HT 3	VH 24
$3\frac{1}{2}$	$7\frac{7}{8}$	4	SFH $3\frac{1}{2}$	HW $3\frac{1}{2}$	HT $3\frac{1}{2}$	VH 28
4	9 [illegible]	$4\frac{1}{2}$	SFH 4	HW 4	HT 4E	VH 32
$4\frac{1}{2}$	$10\frac{5}{16}$	5	SFH $4\frac{1}{2}$	HW $4\frac{1}{2}$	HT $4\frac{1}{2}$E	—
5	$11\frac{7}{16}$	$5\frac{3}{8}$	SFH 5	HW 5	HT 5E	—
$5\frac{1}{2}$	$11\frac{15}{16}$	$5\frac{3}{8}$	SFH $5\frac{1}{2}$	HW $5\frac{1}{2}$	HT $5\frac{1}{2}$E	—
6	$13\frac{3}{4}$	$6\frac{3}{4}$	SFH 6	HW 6	HT 6E	—

TABLE No. 10

LIGHT TYPE

SINGLE-THRUST BALL BEARINGS WITH FLAT SEATINGS (FIG. 21) ENGLISH SIZES

Dimensions (in.) Bore	O.D.	Width	B.S.I.	Hoffmann	R. & M.	SKF.	Fischer
1/4	13/16	3/8	SFL 1/4	W 1/4	LT 1/4		W 1/4
5/16	1	17/32	SFL 5/16	W 5/16	LT 5/16	O 2 1/2	W 5/16
3/8	1	17/32	SFL 3/8	W 3/8	LT 3/8	O 3	W 3/8
7/16	1 9/32	[illegible]	SFL 7/16	W 7/16	LT 7/16	O 3 1/2	W 7/16
1/2	1 9/32	[illegible]	SFL 1/2	W 1/2	LT 1/2	O 4	W 1/2
9/16	1 13/32	[illegible]	SFL 9/16	W 9/16	LT 9/16	O 4 1/2	W 9/16
5/8	1 13/32	[illegible]	SFL 5/8	W 5/8	LT 5/8	O 5	W 5/8
3/4	1 17/32	[illegible]	SFL 3/4	W 3/4	LT 3/4	O 6	W 3/4
7/8	1 21/32	[illegible]	SFL 7/8	W 7/8	LT 7/8	O 7	W 7/8
1	1 25/32	[illegible]	SFL 1	W 1	LT 1	O 8	W 1
1 1/8	1 29/32	[illegible]	SFL 1 1/8	W 1 1/8	LT 1 1/8	O 9	W 1 1/8
1 1/4	2 3/32	23/32	SFL 1 1/4	W 1 1/4	LT 1 1/4	O 10	W 1 1/4
1 3/8	2 7/32	23/32	SFL 1 3/8	W 1 3/8	LT 1 3/8	O 11	W 1 3/8
1 1/2	2 11/32	23/32	SFL 1 1/2	W 1 1/2	LT 1 1/2	O 12	W 1 1/2
1 5/8	2 15/32	23/32	SFL 1 5/8	W 1 5/8	LT 1 5/8	O 13	W 1 5/8
1 3/4	2 11/16	3/4	SFL 1 3/4	W 1 3/4	LT 1 3/4	O 14	W 1 3/4
1 7/8	2 13/16	3/4	SFL 1 7/8	W 1 7/8	LT 1 7/8	O 15	W 1 7/8
2	2 31/32	3/4	SFL 2	W 2	LT 2	O 16	W 2
2 1/8	3 7/32	7/8	SFL 2 1/8	W 2 1/8	LT 2 1/8	O 17	W 2 1/8
2 1/4	3 11/32	7/8	SFL 2 1/4	W 2 1/4	LT 2 1/4	O 18	W 2 1/4
2 3/8	3 19/32	1	SFL 2 3/8	W 2 3/8	LT 2 3/8	O 19	W 2 3/8
2 1/2	3 23/32	1	SFL 2 1/2	W 2 1/2	LT 2 1/2	O 20	W 2 1/2
2 5/8	3 27/32	1	SFL 2 5/8	W 2 5/8	LT 2 5/8	O 21	W 2 5/8
2 3/4	4 1/32	1	SFL 2 3/4	W 2 3/4	LT 2 3/4	O 22	W 2 3/4
2 7/8	4 5/32	1	SFL 2 7/8	W 2 7/8	LT 2 7/8	O 23	W 2 7/8
3	4 [illegible]	1 1/16	SFL 3	W 3	LT 3	O 24	W 3
3 1/8	4 [illegible]	1 1/16	—	W 3 1/8	LT 3 1/8	—	W 3 1/8
3 1/4	4 13/16	1 [illegible]	SFL 3 1/4	W 3 1/4	LT 3 1/4	O 26	W 3 1/4
3 3/8	4 15/16	1 [illegible]	—	W 3 3/8	LT 3 3/8	—	W 3 3/8
3 1/2	5 1/16	1 [illegible]	SFL 3 1/2	W 3 1/2	LT 3 1/2	O 28	W 3 1/2
3 5/8	5 3/16	1 [illegible]	—	W 3 5/8	LT 3 5/8	—	W 3 5/8
3 3/4	5 5/16	1 [illegible]	SFL 3 3/4	W 3 3/4	LT 3 3/4	O 30	W 3 3/4
3 7/8	5 11/16	1 [illegible]	—	W 3 7/8	LT 3 7/8	—	W 3 7/8
4	5 13/16	1 [illegible]	SFL 4	W 4	LT 4E	O 32	W 4
4 1/4	6 5/16	1 [illegible]	—	W 4 1/4	LT 4 1/4E	—	W 4 1/4
4 1/2	6 9/16	1 [illegible]	SFL 4 1/2	W 4 1/2	LT 4 1/2E	O 36	W 4 1/2
4 3/4	7 1/16	2	—	W 4 3/4	LT 4 3/4E	—	W 4 3/4
5	7 5/16	2	SFL 5	W 5	LT 5E	O 40	W 5
5 1/2	8 1/16	2 3/16	SFL 5 1/2	W 5 1/2	LT 5 1/2E	O 44	W 5 1/2
6	8 11/16	2 3/8	SFL 6	W 6	LT 6E	O 48	W 6

NOTE.—Bearings up to and including 1 7/8-in. bore, Hoffmann, R. & M. and Fischer have equal races as B.S.I. Type A, while SKF. are as B.S.I. Type B.

The Tables numbered 1 to 13 inclusive dealing with bearing sizes and makers' symbols have necessarily had to be restricted to the more popular sizes, types, and makes of bearings.

TABLE NO. 11

LIGHT TYPE—DOUBLE-THRUST BALL BEARINGS WITH FLAT SEATINGS, ENGLISH SIZES

Without Sleeves (Fig. 23)

Overall Dimensions (in.)			*Symbols*			
Bore	*O.D.*	*Width*	*B.S.I.*	*Hoff-mann*	*R. & M.*	*SKF.*
1/4	1 1/16	11/16	DFL 1/4	WD 1	DLT 1/4	—
3/8	1 1/4	15/16	DFL 3/8	WD 3	DLT 3/8	DL 3
1/2	1 9/16	1 1/8	DFL 1/2	WD 5	DLT 1/2	DL 4
5/8	1 11/16	1 1/8	DFL 5/8	WD 7	DLT 5/8	DL 5
3/4	1 13/16	1 1/8	DFL 3/4	WD 8	DLT 3/4	DL 6
7/8	1 15/16	1 1/8	DFL 7/8	WD 9	DLT 7/8	DL 7
1	2 1/16	1 1/8	DFL 1	WD 10	DLT 1	DL 8
1 1/8	2 3/16	1 1/8	DFL 1 1/8	WD 11	DLT 1 1/8	DL 9
1 1/4	2 7/16	1 1/4	DFL 1 1/4	WD 12	DLT 1 1/4	DL 10
1 3/8	2 5/8	1 1/4	DFL 1 3/8	WD 12 1/2	DLT 1 3/8	DL 11
1 1/2	2 3/4	1 1/4	DFL 1 1/2	WD 13	DLT 1 1/2	DL 12
1 5/8	2 7/8	1 1/4	DFL 1 5/8	WD 13 1/2	DLT 1 5/8	DL 13
1 3/4	3 1/16	1 5/16	DFL 1 3/4	WD 14	DLT 1 3/4	DL 14
2	3 5/16	1 5/16	DFL 2	WD 15	DLT 2	DL 16
2 1/8	3 5/8	1 9/16	DFL 2 1/8	WD 15 1/2	DLT 2 1/8	DL 17
2 1/4	3 3/4	1 9/16	DFL 2 1/4	WD 16	DLT 2 1/4	DL 18
2 3/8	4	1 3/4	DFL 2 3/8	WD 16 1/2	DLT 2 3/8	DL 19
2 1/2	4 1/8	1 3/4	DFL 2 1/2	WD 17	DLT 2 1/2	DL 20
2 5/8	4 1/4	1 3/4	DFL 2 5/8	WD 17 1/2	DLT 2 5/8	DL 21
2 3/4	4 1/2	1 3/4	DFL 2 3/4	WD 18	DLT 2 3/4	DL 22
2 7/8	4 5/8	1 3/4	DFL 2 7/8	WD 18 1/2	DLT 2 7/8	DL 23
3	4 13/16	2	DFL 3	WD 19	DLT 3	DL 24
3 1/4	5 1/4	2 1/4	DFL 3 1/4	WD 19 1/2	DLT 3 1/4	DL 26
3 1/2	5 1/2	2 1/4	DFL 3 1/2	WD 20	DLT 3 1/2	DL 28
3 3/4	5 3/4	2 1/4	DFL 3 3/4	WD 20 1/2	DLT 3 3/4	DL 30
4	6 1/4	2 1/2	DFL 4	WD 21	DLT 4E	DL 32
4 1/2	7	3 1/16	DFL 4 1/2	WD 22	DLT 4 1/2E	DL 36
5	7 3/4	3 9/16	DFL 5	WD 23	DLT 5E	DL 40
5 1/2	8 1/2	3 7/8	DFL 5 1/2	WD 23 1/2	DLT 5 1/2E	—
6	9 1/4	4 1/8	DFL 6	WD 24	DLT 6E	—

With Sleeves (Fig. 24)

Overall Dimensions (in.)			*Symbols*			
Bore	*O.D.*	*Width*	*B.S.I.*	*Hoff-mann*	*R. & M.*	*SKF.*
—	—	—	—	—	—	—
—	—	—	—	—	—	—
1/4	1 9/16	1 9/16	DSL 1/4	WS 5	DLTS 1/4	—
3/8	1 11/16	1 9/16	DSL 3/8	WS 7	DLTS 3/8	DLS 5
1/2	1 13/16	1 9/16	DSL 1/2	WS 8	DLTS 1/2	DLS 6
5/8	1 15/16	1 9/16	DSL 5/8	WS 9	DLTS 5/8	DLS 7
3/4	2 1/16	1 11/16	DSL 3/4	WS 10	DLTS 3/4	DLS 8
7/8	2 3/16	1 11/16	DSL 7/8	WS 11	DLTS 7/8	DLS 9
1	2 7/16	1 13/16	DSL 1	WS 12	DLTS 1	DLS 10
1 1/8	2 5/8	1 13/16	DSL 1 1/8	WS 12 1/2	DLTS 1 1/8	DLS 11
1 1/4	2 3/4	1 13/16	DSL 1 1/4	WS 13	DLTS 1 1/4	DLS 12
1 3/8	2 7/8	1 13/16	DSL 1 3/8	WS 13 1/2	DLTS 1 3/8	DLS 13
1 1/2	3 1/16	1 7/8	DSL 1 1/2	WS 14	DLTS 1 1/2	DLS 14
1 5/8	3 5/16	2	DSL 1 5/8	WS 15	DLTS 1 5/8	DLS 16
1 3/4	3 5/8	2 1/4	DSL 1 3/4	WS 15 1/2	DLTS 1 3/4	DLS 17
1 7/8	3 3/4	2 1/4	DSL 1 7/8	WS 16	DLTS 1 7/8	DLS 18
2	4	2 7/16	DSL 2	WS 16 1/2	DLTS 2	DLS 19
2 1/8	4 1/8	2 7/16	DSL 2 1/8	WS 17	DLTS 2 1/8	DLS 20
2 1/4	4 1/4	2 7/16	DSL 2 1/4	WS 17 1/2	DLTS 2 1/4	DLS 21
2 3/8	4 1/2	2 7/16	DSL 2 3/8	WS 18	DLTS 2 3/8	DLS 22
2 1/2	4 5/8	2 7/16	DSL 2 1/2	WS 18 1/2	DLTS 2 1/2	DLS 23
2 5/8	4 13/16	2 3/4	DSL 2 5/8	WS 19	DLTS 2 5/8	DLS 24
2 3/4	5 1/4	3 1/8	DSL 2 3/4	WS 19 1/2	DLTS 2 3/4	DLS 26
3	5 1/2	3 1/8	DSL 3	WS 20	DLTS 3	DLS 28
3 1/4	5 3/4	3 1/8	DSL 3 1/4	WS 20 1/2	DLTS 3 1/4	DLS 30
3 1/2	6 1/4	3 3/8	DSL 3 1/2	WS 21	DLTS 3 1/2	DLS 32
4	7	4	DSL 4	WS 22	DLTS 4E	DLS 36
4 1/2	7 3/4	4 5/8	DSL 4 1/2	WS 23	DLTS 4 1/2E	DLS 40
5	8 1/2	5	DSL 5	WS 23 1/2	DLTS 5E	—
5 1/2	9 1/4	5 1/4	DSL 5 1/2	WS 24	DLTS 5 1/2E	—

TABLE No. 12

MEDIUM TYPE—DOUBLE-THRUST BALL BEARINGS WITH FLAT SEATINGS, ENGLISH SIZES

Without Sleeves (Fig. 23)

Overall Dimensions (in.)			*Symbols*			
Bore	*O.D.*	*Width*	*B.S.I.*	*Hoffmann*	*R. & M.*	*SKF.*
$\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{1}{4}$	DFM $\frac{3}{4}$	MD 8	DMT $\frac{3}{4}$	D 6
$\frac{7}{8}$	$2\frac{1}{8}$	$1\frac{5}{16}$	DFM $\frac{7}{8}$	MD 9	DMT $\frac{7}{8}$	D 7
1	$2\frac{1}{4}$	$1\frac{5}{16}$	DFM 1	MD 10	DMT 1	D 8
$1\frac{1}{8}$	$2\frac{1}{2}$	$1\frac{9}{16}$	DFM $1\frac{1}{8}$	MD 11	DMT $1\frac{1}{8}$	D 9
$1\frac{1}{4}$	$2\frac{3}{4}$	$1\frac{3}{4}$	DFM $1\frac{1}{4}$	MD 12	DMT $1\frac{1}{4}$	D 10
$1\frac{1}{2}$	$3\frac{1}{4}$	2	DFM $1\frac{1}{2}$	MD 13	DMT $1\frac{1}{2}$	D 12
$1\frac{3}{4}$	$3\frac{3}{4}$	$2\frac{1}{4}$	DFM $1\frac{3}{4}$	MD 14	DMT $1\frac{3}{4}$	D 14
2	$4\frac{1}{8}$	$2\frac{1}{2}$	DFM 2	MD 15	DMT 2	D 26
$2\frac{1}{4}$	$4\frac{7}{8}$	3	DFM $2\frac{1}{4}$	MD 16	DMT $2\frac{1}{4}$	D 18
$2\frac{1}{2}$	$5\frac{3}{8}$	$3\frac{1}{2}$	DFM $2\frac{1}{2}$	MD 17	DMT $2\frac{1}{2}$	D 20
$2\frac{3}{4}$	$5\frac{5}{8}$	$3\frac{1}{2}$	DFM $2\frac{3}{4}$	MD 18	DMT $2\frac{3}{4}$	D 22
3	$6\frac{1}{4}$	4	DFM 3	MD 19	DMT 3	—
$3\frac{1}{2}$	$7\frac{1}{4}$	$4\frac{1}{2}$	DFM $3\frac{1}{2}$	MD 20	DMT $3\frac{1}{2}$	—
4	$8\frac{1}{8}$	5	DFM 4	MD 21	DMT 4	—
$4\frac{1}{2}$	$9\frac{1}{4}$	6	DFM $4\frac{1}{2}$	MD 22	DMT $4\frac{1}{2}$	—
5	$10\frac{3}{8}$	7	DFM 5	MD 23	DMT 5	—
$5\frac{1}{2}$	$11\frac{1}{4}$	$7\frac{1}{2}$	DFM $5\frac{1}{2}$	MD $23\frac{1}{2}$	DMT $5\frac{1}{2}$	—
6	12	8	DFM 6	MD 24	DMT 6	—

With Sleeves (Fig. 24)

Overall Dimensions (in.)			*Symbols*			
Bore	*O.D.*	*Width*	*B.S.I.*	*Hoffmann*	*R. & M.*	*SKF.*
$\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{3}{4}$	DSM $\frac{1}{2}$	MX 8	DMTS $\frac{1}{2}$	DS 6
$\frac{5}{8}$	$2\frac{1}{8}$	$1\frac{15}{16}$	DSM $\frac{5}{8}$	MX 9	DMTS $\frac{5}{8}$	DS 7
$\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{15}{16}$	DSM $\frac{3}{4}$	MX 10	DMTS $\frac{3}{4}$	DS 8
$\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{3}{16}$	DSM $\frac{7}{8}$	MX 11	DMTS $\frac{7}{8}$	DS 9
1	$2\frac{3}{4}$	$2\frac{1}{2}$	DSM 1	MX 12	DMTS 1	DS 10
$1\frac{1}{4}$	$3\frac{1}{4}$	$2\frac{3}{4}$	DSM $1\frac{1}{4}$	MX 13	DMTS $1\frac{1}{4}$	DS 12
$1\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{4}$	DSM $1\frac{1}{2}$	MX 14	DMTS $1\frac{1}{2}$	DS 14
$1\frac{5}{8}$	$4\frac{1}{8}$	$3\frac{1}{2}$	DSM $1\frac{5}{8}$	MX 15	DMTS $1\frac{5}{8}$	DS 16
$1\frac{3}{4}$	$4\frac{7}{8}$	4	DSM $1\frac{3}{4}$	MX 16	DMTS $1\frac{3}{4}$	DS 18
2	$5\frac{3}{8}$	$4\frac{3}{4}$	DSM 2	MX 17	DMTS 2	DS 20
$2\frac{1}{4}$	$5\frac{5}{8}$	$4\frac{3}{4}$	DSM $2\frac{1}{4}$	MX 18	DMTS $2\frac{1}{4}$	DS 22
$2\frac{1}{2}$	$6\frac{1}{4}$	$5\frac{1}{4}$	DSM $2\frac{1}{2}$	MX 19	DMTS $2\frac{1}{2}$	—
3	$7\frac{1}{4}$	$5\frac{3}{4}$	DSM 3	MX 20	DMTS 3	—
$3\frac{1}{2}$	$8\frac{1}{8}$	$6\frac{1}{2}$	DSM $3\frac{1}{2}$	MX 21	DMTS $3\frac{1}{2}$	—
4	$9\frac{1}{4}$	$7\frac{1}{2}$	DSM 4	MX 22	DMTS 4E	—
$4\frac{1}{2}$	$10\frac{3}{8}$	$8\frac{3}{4}$	DSM $4\frac{1}{2}$	MX 23	DMTS $4\frac{1}{2}$E	—
5	$11\frac{1}{4}$	$9\frac{1}{2}$	DSM 5	MX $23\frac{1}{2}$	DMTS 5E	—
$5\frac{1}{2}$	12	10	DSM $5\frac{1}{2}$	MX 24	DMTS $5\frac{1}{2}$E	—

TABLE NO. 13

HEAVY TYPE—DOUBLE-THRUST BALL BEARINGS WITH FLAT SEATINGS, ENGLISH SIZES

Without Sleeves (Fig. 23) Overall Dimensions (in.)			Without Sleeves (Fig. 23) Symbols				With Sleeves (Fig. 24) Overall Dimensions (in.)			With Sleeves (Fig. 24) Symbols		
Bore	O.D.	Width	B.S.I.	Hoffmann	R. & M.	S.K.F.	Bore	O.D.	Width	B.S.I.	Hoffmann	R. & M.
$\frac{1}{4}$	$1\frac{1}{4}$	$\frac{15}{16}$	DFH $\frac{1}{4}$	HD 1	DHT $\frac{1}{4}$	DH 2	—	—	—	—	—	—
$\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{32}$	DFH $\frac{3}{8}$	HD 3	DHT $\frac{3}{8}$	DH 3	—	—	—	—	—	—
$\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{4}$	DFH $\frac{1}{2}$	HD 5	DHT $\frac{1}{2}$	DH 4	$\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{4}$	DSH $\frac{1}{4}$	HX 5	DHTS $\frac{1}{4}$
$\frac{5}{8}$	2	$1\frac{5}{16}$	DFH $\frac{5}{8}$	HD 7	DHT $\frac{5}{8}$	DH 5	$\frac{3}{8}$	2	$1\frac{15}{16}$	DSH $\frac{3}{8}$	HX 7	DHTS $\frac{3}{8}$
$\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{17}{32}$	DFH $\frac{3}{4}$	HD 8	DHT $\frac{3}{4}$	DH 6	$\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{5}{32}$	DSH $\frac{1}{2}$	HX 8	DHTS $\frac{1}{2}$
$\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{3}{4}$	DFH $\frac{7}{8}$	HD 9	DHT $\frac{7}{8}$	DH 7	$\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$	DSH $\frac{5}{8}$	HX 9	DHTS $\frac{5}{8}$
1	$2\frac{7}{8}$	2	DFH 1	HD 10	DHT 1	DH 8	$\frac{3}{4}$	$2\frac{7}{8}$	$2\frac{3}{4}$	DSH $\frac{3}{4}$	HX 10	DHTS $\frac{3}{4}$
$1\frac{1}{8}$	$3\frac{1}{8}$	$2\frac{5}{16}$	DFH $1\frac{1}{8}$	HD 11	DHT $1\frac{1}{8}$	DH 9	$\frac{7}{8}$	$3\frac{1}{8}$	$3\frac{3}{16}$	DSH $\frac{7}{8}$	HX 11	DHTS $\frac{7}{8}$
$1\frac{1}{4}$	$3\frac{1}{2}$	$2\frac{5}{8}$	DFH $1\frac{1}{4}$	HD 12	DHT $1\frac{1}{4}$	DH 10	1	$3\frac{1}{2}$	$3\frac{5}{8}$	DSH 1	HX 12	DHTS 1
$1\frac{1}{2}$	4	$3\frac{1}{16}$	DFH $1\frac{1}{2}$	HD 13	DHT $1\frac{1}{2}$	DH 12	$1\frac{1}{4}$	4	$4\frac{3}{16}$	DSH $1\frac{1}{4}$	HX 13	DHTS $1\frac{1}{4}$
$1\frac{3}{4}$	$4\frac{1}{2}$	$3\frac{1}{2}$	DFH $1\frac{3}{4}$	HD 14	DHT $1\frac{3}{4}$	DH 14	$1\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{5}{8}$	DSH $1\frac{1}{2}$	HX 14	DHTS $1\frac{1}{2}$
2	$5\frac{1}{4}$	4	DFH 2	HD 15	DHT 2	DH 16	$1\frac{5}{8}$	$5\frac{1}{4}$	$5\frac{1}{4}$	DSH $1\frac{5}{8}$	HX 15	DHTS $1\frac{5}{8}$
$2\frac{1}{4}$	$5\frac{7}{8}$	$4\frac{7}{16}$	DFH $2\frac{1}{4}$	HD 16	DHT $2\frac{1}{4}$	DH 18	$1\frac{3}{4}$	$5\frac{7}{8}$	$5\frac{11}{16}$	DSH $1\frac{3}{4}$	HX 16	DHTS $1\frac{3}{4}$
$2\frac{1}{2}$	$6\frac{3}{8}$	$4\frac{7}{8}$	DFH $2\frac{1}{2}$	HD 17	DHT $2\frac{1}{2}$	DH 20	2	$6\frac{3}{8}$	$6\frac{1}{4}$	DSH 2	HX 17	DHTS 2
3	$7\frac{1}{2}$	$5\frac{7}{8}$	DFH 3	HD 19	DHT 3	DH 24	$2\frac{1}{2}$	$7\frac{1}{2}$	$7\frac{1}{2}$	DSH $2\frac{1}{2}$	HX 19	DHTS $2\frac{1}{2}$
$3\frac{1}{2}$	$8\frac{3}{4}$	7	DFH $3\frac{1}{2}$	HD 20	DHT $3\frac{1}{2}$	DH 28	3	$8\frac{3}{4}$	$8\frac{3}{4}$	DSH 3	HX 20	DHTS 3
4	10	$7\frac{7}{8}$	DFH 4	HD 21	DHT 4E	DH 32	$3\frac{1}{2}$	10	$9\frac{7}{8}$	DSH $3\frac{1}{2}$	HX 21	DHTS $3\frac{1}{2}$

SETTING OUT CAMS

To illustrate the method of laying out any set of cams, the component shown on page 440 (Fig. 4) has been chosen, using for example the $\frac{5}{8}$-in. B.S.A. automatic.

It is essential to have the handbook of the automatic for which the cams are intended. This gives spindle speeds, surface speeds for various diameters of stock, machine capacity, minimum time required to index, feed stock and change speed, and the number of cycle times (in seconds) available. It is also useful to have a speeds and feeds chart. The engineer should, however, be able to estimate his own speeds and feeds, but the speeds and feeds tabulated have been found most suitable.

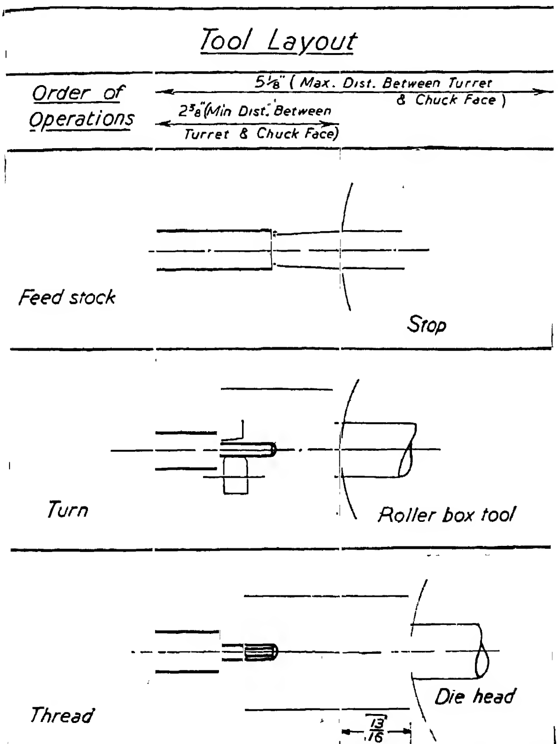


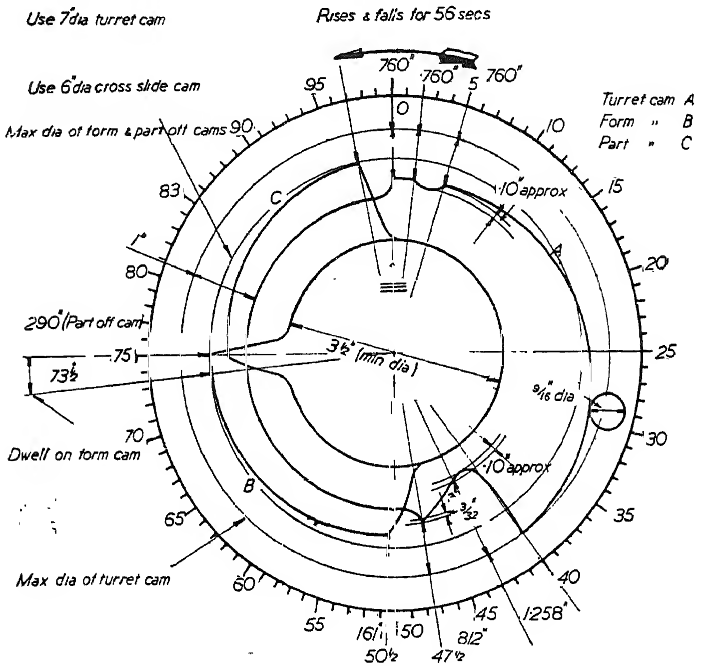
Fig. 1.—Tool layout for component shown on page 440. (See table and illustration.)

Turret and Cross-slide Travel.—The order of operations and types of tools to be used are first tabulated, after which the calculations are made. To the turret travel, 0·010-in. approach must be added, and to the cross-slide travel 0·005-in. approach added. This allows the tools to start the cutting operation

without any jolting on the work. The parting-off operation is an exception to the rule. To the part-off travel, 0·005-in. approach plus 0·005 in. past centre of work, plus 0·030 in. (angle on tool) must be added. (See Fig. 2.)

Thirty thousandths on the parting-off tool is a maximum, and in most cases it is less than this.

Travel on part-off tool = 0·250 in. plus 0·005 in. plus 0·005 in. plus 0·030 in. = 0·290 in.



Feed Gears				Spindle Gears			
A	B	C	D	A	B	C	D
58	86	32	60	36	74	67	43

Fig. 1a.—Layout of cam for component shown on page 440.

It will be seen from the table on page 440 that two columns are devoted to actual revs. and idle revs. Actual revs. result in actual work, i.e. threading, turning, etc.; idle revs. do not result in actual work, but are necessary for indexing the machine, etc.

To find actual revs.:

$$\text{Actual revs.} = \frac{\text{Travel}}{\text{Feed per rev.}}$$

For example, actual revs. required to part-off $= \frac{0{\cdot}290}{0{\cdot}002} = 145.$

Indexing.—After tabulating types of tools, travel, feed and actual revs., the number of hundredths of cam surface required for indexing must be determined. The turret cam is divided into 100 equal parts; each revolution of the cam produces one component. The turret is required to index during the production of a component; thus a proportion of cam is required for indexing. The turret tools should be drawn in roughly and to scale, as shown in the tool layout on page 437 (Fig. 1). If the back of the tool extends beyond the line indicating minimum distance from the chuck face, the extension should be measured, and the lobe concerned should be dropped back that distance from the maximum diameter of the cam.

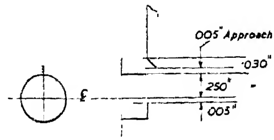


Fig. 2.—The parting-off operation.

The lead cam actuates the movement of the turret through a roller which is mounted on a swing arm. As the machine indexes, the roller drops into the root of each cam lobe. By marking the root of each cam lobe on the cam, the 1/100ths of cam required to index can easily be deduced. (See Fig. 3.)

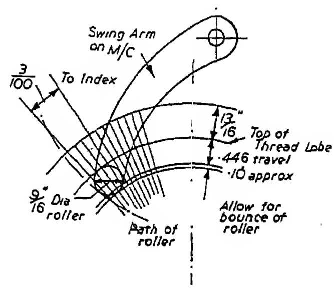


Fig. 3.—By marking the root of each cam lobe on the cam, the 1-100ths of cam required to index can be deduced.

One-tenth of an inch below the travel should be allowed for the bounce of the roller. As the roller swings into the root of the lobe after indexing, there is a certain amount of bounce. This is accounted for by the 0·10-in. dimension, which prevents the unnecessary jolting of the tool on the next operation. It is usual to estimate 2/100ths of cam surface for feeding the stock. The reader must fully realise that laying-out a set of cams is a trial-and-error problem, and that an adjustment of figures is more than likely to be necessary after the first attempt.

Estimating Cycle Time.—To find the cycle time, the following procedure must be adopted:

14/100ths of cam surface are idle.

86/100ths of cam surface are actual.

$$\therefore \frac{86}{100} = 566 \text{ act. revs.}$$

$$\frac{1}{100} = \frac{566}{86} \text{ revs.} = 6{\cdot}58 \text{ revs.}$$

As there are 100/100ths of cam surface the lead cam revolves once for each component produced.

Revs. per piece = 658.

The machine runs at 709 r.p.m. = 11·8 r.p.s. (revs. per sec.).

$$\text{Cycle time per piece} = \frac{658}{11{\cdot}8} = 56 \text{ secs.}$$

Assuming that the turning operation has a 0·003-in. feed, this results in 253 actual revs.

Thus, in the first calculations:

$$\frac{86}{100} = 587 \text{ revs. actual.}$$

$$\frac{1}{100} = \frac{587}{86} \text{ revs.} = 6{\cdot}82 \text{ revs.}$$

∴ Revs. per piece = 682.

Speed of machine = 11·8 revs. per sec.

$$\text{Cycle time} = \frac{682}{11{\cdot}8} \text{ secs.} = 58 \text{ secs.}$$

The operator's handbook shows that 58 secs. is not in the available cycle times. The cycle time must be either reduced or lengthened accordingly. If a 56-cycle time is decided upon:

∴ Revs. required = 56 × 11·8 per piece = 661.

Therefore, 682 − 661 revs. must be subtracted from whatever operation may be thought necessary. In this case the 21 revs. are subtracted from the turning operation, thus altering the feed to 0·0032 per rev.

After finding the cycle time, the actual 1/100th and idle revs. can easily be calculated.

$$1/100\text{th} = 6{\cdot}58 \text{ revs.}$$

$$\frac{\text{Act. revs.}}{6{\cdot}58} = \text{actual } 1/100\text{th.}$$

Similarly, idle 1/100th × 6·58 = idle revs.

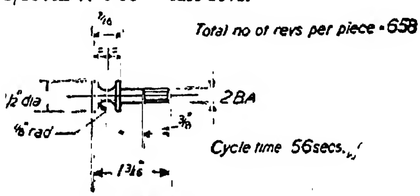


Fig. 4.—Component for cam shown on page 438.

CAM CALCULATIONS

Material—High-tensile Steel. Size—½-in.-diam. Ground Bar. Machine—⅝-in. B.S.A.

Cutting Speed for Turning—93 ft. per min. Machine Revs.—709 per min.
Cutting Speed for Threading—17 ft. per min. Machine Revs.—345 per min.

	Order of Operations	Travel	Feed	Actual Revs.	Idle Revs.	Actual 100ths	Idle 100ths
		in.	in.				
1	Feed stock	—	—	—	13	—	2
2	Index	—	—	—	20	—	3·5
3	Turn	0·760	0·0032	232	—	35	0·40
4	Index	—	—	—	20	—	3·43
5	Thread	0·446 (14 thds.)	0·0319	28 Fast Speed 14 Slow Speed	—	4½	0·475
6	Clear	—	—	—	20	—	3·505
7	Form	0·161	0·001	161	—	24½	0·75
8	Part-off	0·290	0·002	145	—	22	0·97
9	Clear	—	—	—	20	—	3·100

A minimum time is allowed for indexing and to feed stock. In most modern machines this minimum time rarely exceeds $\frac{1}{2}$ sec. Taking the previous example:

Allowance of 2/100ths has been made to feed stock.
2/100ths = 13 revs.
Machine speed = 11·8 revs. per sec.
2/100ths to feed stock and 3/100ths to index is well within the limits.

It is possible to cut down the cycle time by using this form of check.

There are three important points to bear in mind. Firstly, clearance between operations; secondly, dwell on form cams; and thirdly, the thread allowance for self-opening die heads.

Clearance between Operations.—From the cam sheet it can be seen that there are clearances between the threading and the forming operations. It is essential to have clearance between these; thus, in the one case the die head is well away from the work when the form tool starts to cut, and in the other, the parting-off tool is well away from the work when the stock is fed out.

In all similar cases it must be ensured that the turret and cross slides do not foul, neither should the stock be fed out before the parting-off tool has been cleared out of the way.

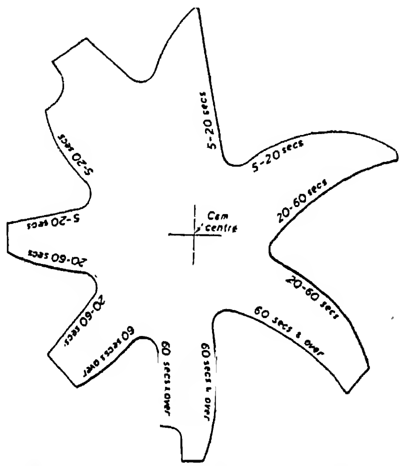


Fig. 5.—A typical template for ascertaining cam rises and falls.

Dwell on Form Cams.—No allowance has been made for a dwell on the form cam, although the form cam is drawn with $1\frac{1}{2}$/100ths' dwell. If a generous feed is given on the forming operation, it is far easier to put a dwell on the cam afterwards. For this reason it is usual to allow 8 to 10 revs.' dwell on a forming operation in order to obtain a high finish, although this allowance varies according to the material and finish required. If the calculations have been made, as is the case, a dwell of $1\frac{1}{2}$/100ths (equivalent to about 10 revs.) can be made on the form cam.

Therefore, instead of having $24\frac{1}{2}$/100ths for forming there are only 23/100ths.

1/100th = 6·58 revs.
23/100ths = 151 revs.
0·161-in. travel gives an increased feed of 0·151 revs.
= 0·00106 in. per rev.

Thread-lobe for Self-opening Die Heads.—On automatic screwing machines the die head is forced on to the work by the threading lobe of the lead cam. It then travels along in correct ratio with the spindle speed of the machine. The die head itself is in two parts, being engaged to one another by two pins about $\frac{3}{32}$ in. in length.

For the die head to open, the rear half must remain stationary whilst the front half is pulled out by the screwing action of the job, thus disengaging the pins and opening the die head. The thread lobe is first drawn as calculated; afterwards, a radial line $\frac{3}{32}$ in. from the top of the thread lobe is struck from the cam centre, thus making a dwell. The die head is therefore held stationary $\frac{3}{32}$ in. from the end of the travel, whilst the front half is pulled up the required amount by the job itself, and in doing so opens.

As a guide to the drawing of the cams, it is essential to have the cam template issued by the makers of the machine.

A typical template is shown above in Fig. 5, the convex radii being for cam rises and the concave radii for the falls.

CAM DESIGN FOR AUTOMATIC SCREW MACHINES

The motion depicted in Fig. 6 shows the lead cam A, which revolves in an anti-clockwise direction. The roller B slides along the periphery of the cam and, as it rises or falls with the lobes of the cam, the quadrant C, positioned at the opposite end of the lever, fulcrumed at X, engages with the rack of the slide and transfers the motion of the turret or slide to which it is secured. The return of the slide is governed by the powerful compression spring at D.

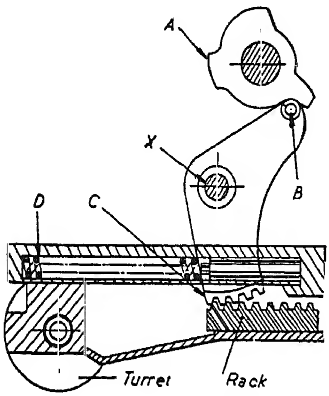


Fig. 6.—The action of a cam.

Principles of Design.—The principle of designing cams is to obtain the number of revolutions of the work spindle for each operation and for each idle movement, i.e. when the tools are withdrawing or indexing. Overlap the operations and the idle movements that can take place simultaneously, and then proportion the balance of spindle revolutions on the surface of the lead cam so that the total of these spindle revolutions equals the full circumference of the cam.

The surface of the cam is made up of a series of lobes connected by a series of drops, and during these spaces the idle movements take place. The cross-slide cams revolve at the same speed as the lead cam, and operations performed by cross-slide tools are laid out on these.

When the respective tools are not operating, the cams are milled down in order that the tools are withdrawn out of the way ; a rise on the cam surface automatically brings them back into position to commence an operation at some specified moment.

Surface of the Cam.—The surface of the cam is divided equally into hundredths, which represents the total number of spindle revolutions to complete a piece. When this has been done the following steps should be followed :

(1) Determine the sequence of operations and the necessary tools required.
(2) Determine the spindle speeds.
(3) Determine the feed and throw (or travel) of each tool.
(4) Determine the revolutions required for each operation.
(5) Determine the revolutions required for each idle movement.
(6) Total up the number of revolutions.
(7) Readjust the number of revolutions to total the actual number available on the machine.
(8) Calculate the number of hundredths required for each movement and the number of revolutions.
(9) Lay out the tools to determine the height of the cam lobes.

For purposes of illustration let it be assumed that the stud shown on the cam sheet is to be made complete on an automatic machine, then the work sheet would be laid out as shown in Fig. 7.

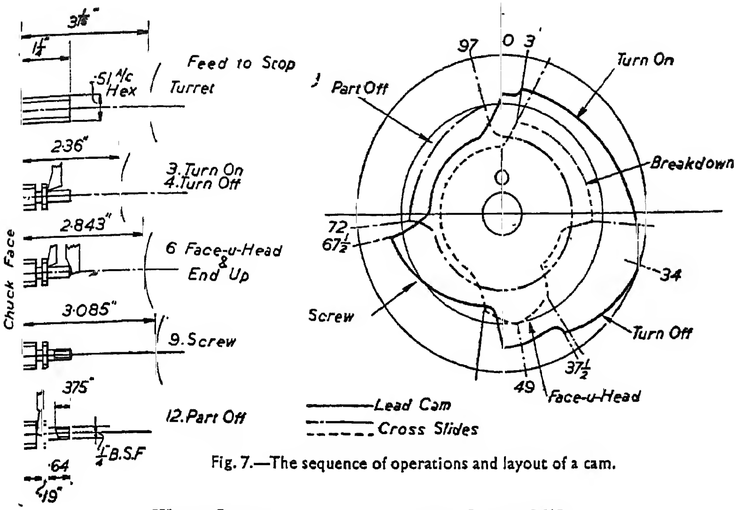


Fig. 7.—The sequence of operations and layout of a cam.

WORK SHEET FOR .... AUTO. SCREW M/C.

Part No. DX137.
Material—M.S.
Spindle Speeds: Turning, 1,200. Screwing, 150.

Sequence of Operations	*Throw*	*Feed per Rev.*	*Revs. for Operation*	*Hundredths*		
				reqd.	*from*	*to*
(1) Feed . . .	—	—	11	1½	0	1½
(2) Index turret .	—	—	11	1½	1½	3
(3) Turn on . .	0·64	0·0027	237	31	3	34
(4) Turn off . .	0·25	0·01	25	3½	34	37½
(5) Index . .	—	—	30	4	37½	41½
(6) End up . .	0·06	0·0016	38	5	41½	46½
(7) Dwell . .	—	—	7	1	46½	47½
(8) Index and change speed . .	—	—	45	6½	47½	54
(9) Screw . .	0·5	0·0385	104	13½	54	67½
(10) Dwell . .	—	—	7	1	67½	68½
(11) Index and change speed . .	—	—	25	3½	68½	72
(12) Part-off . .	0·17	0·0009	188	25	72	97
(13) Index and clear .	—	—	22	3	97	100
Total revolutions .	—	—	760	—	—	—
Time/piece, 38 secs.						

OVERLAPPING OPERATIONS

Break down . .	0·14	0·0006	234	30½	3	33½
Face under head .	0·14	0·003	44	6	40	46
Face off . . .	0·14	0·006	22	3	46	49

Throw of the Tool.—To obtain the throw or travel of each tool and to decide which tool is required, it is advisable to sketch the operational sequence on the actual cam sheet. The formulæ required to determine the figures shown in the work sheet are simple and straightforward, requiring no explanation.

Thus the revolutions required for each operation :

$$\text{No. of revs.} = \frac{\text{Travel of tool}}{\text{Feed per travel}} \quad \therefore \frac{0{\cdot}25}{0{\cdot}010} = 25.$$

The hundredths required :

$$\text{Hundredths} = \frac{\text{Total revolutions}}{\text{No. of revolutions}} = \frac{760}{25}$$
$$= 3\tfrac{1}{2} \text{ (approx.)}.$$

It will be noted that the overlapping operations occur when the cross-slide tools will not interfere with the tools in the turret. For example : it would be impracticable to face under the head with the cross-slide tools when the turning operation, or screwing operation, is in progress ; therefore the facing is done while the turret is indexing, and the facing off occurs during the ending-up operation. This ensures that there is no possibility of the tools colliding.

When using a die head for screwing, the travel is determined from the number of threads required, and a further three or four threads must be added to account for the approach and running off of the die box.

Layout of Cams.—In order to obtain an unimpaired view of the sequence and overlapping of the different tools, it is advisable that all the cams for the same piece be drawn on the same sheet and superimposed on each other. The hundredth intersection line at the top is always taken as zero and the commencement of the operations. The height of the cam lobes is taken from the tool sequence, having fixed the foremost position of all tools. By combining the tool sequence layout for height and the work-sheet dimensions for angular movement, the lead cam can be speedily laid out. The radial rise is, of course, gradual, and the radii are the radius of the arm roller.

To determine the height of the lobes on the cross-slide cams, the outside diameter of the cam represents the centre line of the work spindle ; thus for the cross-slide cams it is necessary to work backwards, starting from the highest point. When the cams have been drawn out it can be seen at a glance where one operation finishes and where the cross slides are working in conjunction with the turret.

CUTTING CAMS ON MILLING MACHINES

There are three methods of cutting cams on milling machines : (1) By mounting a cam-cutting attachment, which has a flat former controlling the motion so that face, peripheral, or cylindrical cams are formed to match. (2) By using an index head, and by a combination of intermittent indexing and vertical table feed, producing the outline. (3) By using the spiral head, gearing it to the table feed screw, and moving the table, which will result in a rotation and simultaneous advance of the cam blank, evolving a spiral lobe.

A crude way of working without a machine is to mark the outline on the blank, drill a procession of holes near the line, and break off, or saw it out, then finish by filing. When very accurate curves are imperative, as in many screw-machine cams, this does not guarantee uniform increase.

Use of Index Head.—A much better scheme consists in mounting the index head on a plain or universal miller, with spindle parallel to and directly underneath the machine spindle. An end mill of the same diameter as the roll is employed. The mill is set at the top of the lobe (see Fig. 8) and the blank is indexed a small amount. Next, the table is fed vertically a distance corresponding to the rise of the lobe in the distance the blank has been indexed, and so on until the edge has been completed. Some filing will be necessary to smooth down the surface, the amount depending on the fineness of the divisions chosen for indexing. For example, to mill a lobe with rise of 1 in. in 8/100ths, equal to $\frac{1}{8}$ in., or 0·125-in. rise

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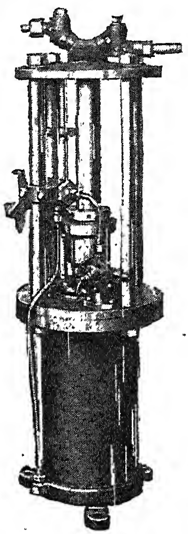

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for each hundredth: if the blank is indexed as much as 1/100th each time, the curve made will require considerable filing. But by indexing only a quarter of a hundredth the rise will be 0·125/4 in. or 0·0312 in. to feed the table, giving more accurate results.

Geared-up Spiral Head.—Very true cutting is obtained by gearing the spiral head to the table screw, producing continuous motion. If a horizontal cutter-spindle is run, and the table fed in line with its axis, there would be no lead action, and the blank would come out concentric. But if the index-head spindle be pointed vertically, and vertical-spindle attachment be driven, the blank will advance towards its mill simultaneously with rotation, and take spiral shape, the lead being the same as that for which the machine is geared. Consequently, by elevating the spiral head to any angle between zero and 90 degrees the amount of lead given to the cam will be between that for which the machine is geared and 0. Therefore, cams with very large range of different leads can be cut with one set of change-gears, and it is a question of finding the angle for setting the head for

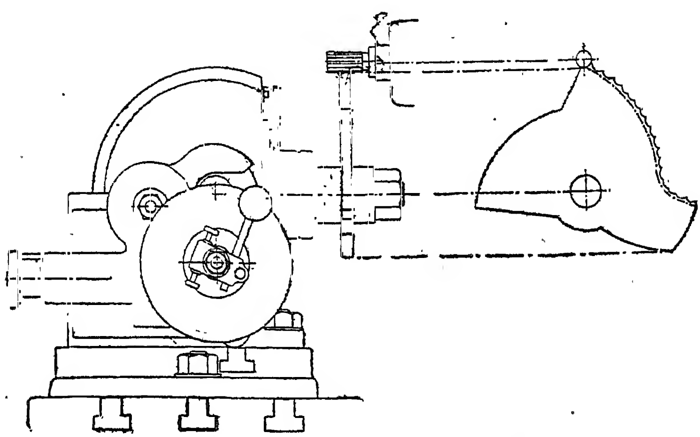


Fig. 8.—Method of milling cam by intermittent settings of table and index spindle.

a given lead. Fig. 9 shows the arrangement. As specimens of procedure, drawings of two cams are given, and the mode of working out the problems.

It is essential first to know the lead of the lobes, that is, the amount of rise of each lobe if continued the full circumference of the cam. This is obtained in the following manner: For cams with the face divided into hundredths, as in Figs. 10 and 11, multiply 100 by the rise of the lobe in inches, and divide by the number of hundredths of circumference occupied by the lobe. For cams which are figured in degrees of circumference, multiply 360 by the rise of the lobe in inches, and divide by the number of degrees of circumference occupied by the lobe. For instance, in Fig. 10 the lobe extends through 91/100ths of the circumference, and has a rise 0·178 in. Then $\frac{100 \times 0{\cdot}178 \text{ in.}}{91} = 0{\cdot}1956$ lead of lobe, or 0·196 in., which is near enough.

As a 0·196-in. lead is much less than 0·67 in., which is the shortest lead regularly obtainable on the machine (though a short lead attachment can be added as extra), the change-gears which will give a lead of 0·67 in. may be used, and the angle of the head may be adjusted so that a lead of 0·196 in. will be produced on the cam

lobe with these change-gears. The rule for this is: divide the given lead of the cam lobe by a lead obtainable on the machine, and the result is the sine of the angle at which to set the head.

Continuing the calculation for the lobe we therefore have:

$$\frac{0{\cdot}196 \text{ in.}}{0{\cdot}67} = 0{\cdot}29253.$$

Therefore 0·29253 is the sine of the correct angle. On referring to a table it will be found that 0·29253 is very near ·29265, which is the sine of an angle of 17

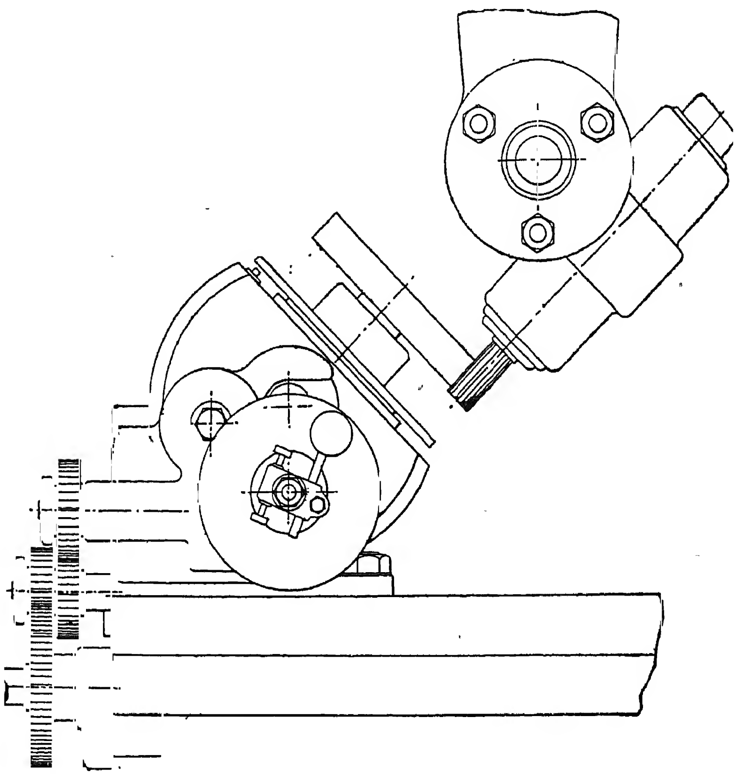


Fig. 9—Accurate method of generating cam by gearing spiral lead to table screw.

degrees and 1 minute. As the spiral head is not graduated closer than quarter degrees, it will do to elevate the head just a very trifle over 17 degrees; then, with the gearing for a lead of 0·67 in., a cam with lead of 0·196 in. will be obtained. The minute errors arising from differences in the deadright settings and those produced by the calculations given are of no moment. The gap in the periphery of Fig. 10, a screw-machine cam, represents the clearance of the cutting tool previous

to the commencement of the throw. It can be drilled or sawn out, and finished by filing, or else milled.

In Fig. 11 the lobe A has a rise of 2·493 in. in 47/100ths, and B a rise of 2·443 in. in 29/100ths. For lobe A the figuring is $\frac{100 \times 2{\cdot}493 \text{ in.}}{47} = 5{\cdot}304$-in. lead. For lobe B the calculation is $\frac{100 \times 2{\cdot}443 \text{ in.}}{29} = 8{\cdot}424$ in.

If there are two or more lobes on a cam the machine is geared for a lead slightly longer than the longest required, which in this case is 8·424 in., then the other lobes are milled without changing the gears. On referring to a table of leads we find a lead of 8·437 in., which is slightly larger than 8·424 in. This gearing is therefore taken, and it is required to find the sine of the angle at which to set the head for lobe B.

$\frac{8{\cdot}424}{8{\cdot}437} = 0{\cdot}99846$ sine of angle at which to set head. Looking at a table of sines and cosines, 0·99846 is found to be the sine of an angle of 86 degrees and 49 minutes. The head, therefore, is set at a trifle over 86¾ degrees.

When lobe B has been milled the head is set for lobe A.

$\frac{5{\cdot}304}{8{\cdot}437} = 0{\cdot}62865$ sine of an angle at which to set head. Referring to the table of sines and cosines we find that 0·62864 (which is near enough to 0·62865) is the sine of an angle of 38 degrees and 57 minutes. The head is therefore set slightly under 39 degrees.

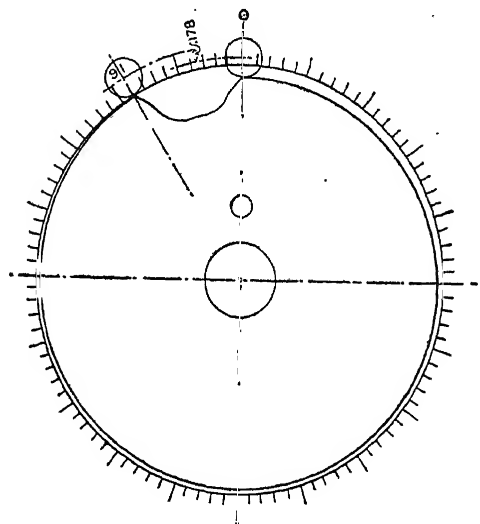


Fig. 10.—Single-lobe cam measured by hundredths around face.

When possible, the setting up should be arranged so that the mill cuts on the lower side of the blank, which has the result of bringing mill and table closer together, with more rigidity. It also prevents chips from crowding the view and obscuring lines on the blank. If the lead of the machine is over 2 in., the automatic feed may be used, but when less than this, feeding should be done by the index crank, to relieve the stress on the spiral head gearing. Of course, in the case of a shape like that in Fig. 11, where considerable stock has to be removed, the outline should be cut out first, by marking-out, drilling, and breaking off nearly to dimensions.

Cam-cutting Attachment.—The Brown and Sharpe attachment does not need any setting up of change-gears, but is self-contained on the table, and depends for its action on a former attached to a worm-wheel placed on the work-spindle. As the worm-wheel is slowly revolved by handle and worm, the former depresses a vertical rack which drives a pinion geared to a horizontal rack in the sliding bed of the attachment, thus imparting the necessary sliding movement. For a cylindrical cam the work-spindle and tailstock lie at right angles to the

cutter-spindle, the centre height being in the same axis. An end mill therefore cuts a cam groove as the blank is rotated, and fed longitudinally. For a peripheral cam or a face cam the work-spindle lies parallel to the cutter-spindle, and as the end mill cuts, the lateral sliding of the attachment bed creates the cam contour. The blank is bolted to a faceplate on the work-spindle. The table of the machine remains always locked in one position.

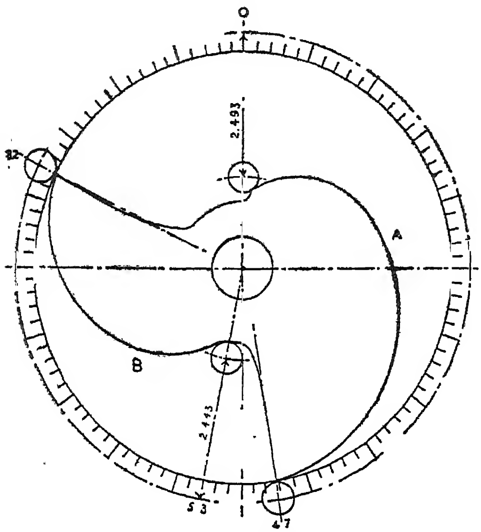


Fig. 11.—Double-lobe cam also measured by hundredths.

The worm may be sometimes driven by means of a belt leading from a small jackshaft to a three-step cone pulley on the worm shaft. The pulley is clutched to the worm in order that either hand or automatic feed can be had by throwing over a lever.

In a cam the motion of which is uniformly accelerated, the follower passes through uniform distances during equal time periods.

For example, if the follower travels 1 length unit for 1 time unit, and 4 length units during the second time unit, it will travel 7 length units during the next time unit, 10 during the next, and so on.

The cams used on automatic screw machines, of the plate type, are usually cut on a milling machine, setting the spiral head either in a vertical plane or at an angle. In the vertical position the lead or rise of the cam for one revolution is equivalent to the lead for which the machine is geared; when set on angle any lead or rise of the cam, less than the lead for which the machine is geared, can be obtained. Thus the cam lead can be varied by changing the inclination of the spiral head; only, of course, within certain limits.

PRODUCTION AND TESTING OF CAMS

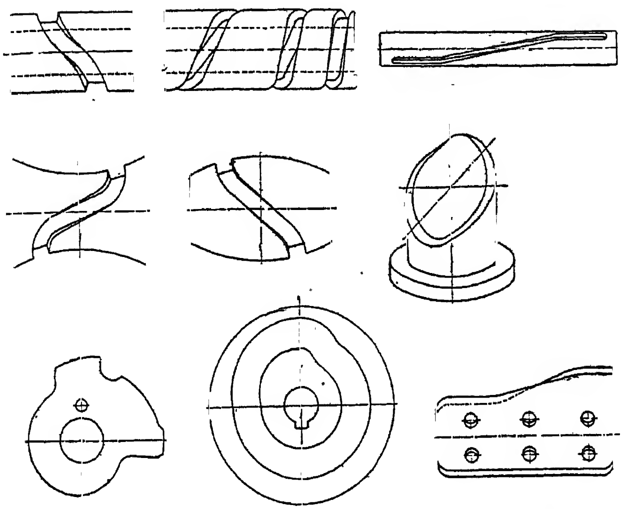
In single production of cams, in particular of those of no great importance, it may suffice to mark the cam profile, mill it according to the marking, and to finish it by filing. Disc cams are tested with the caliper for the minimum and maximum radii. If during operation inaccuracies become evident, the curve has to be readjusted or a new one has to be produced. If only a small number of cam profiles has to be produced, a template of sheet metal is used. Higher accuracy of a cam profile can be obtained only if it is produced on special fixtures, special machines, and accepted after being tested.

In Fig. 11 a number of usual cam profiles are represented, and in the following some special and universal devices will be shown which permit the production of such cams in an economical way. In the production of a cam not only the accurate shape of the cam profile should be copied but the form of the follower movement has to be considered in such a way that the mechanism for the production is the kinematical inversion of the actual working mechanism. This is of main importance for obtaining accurately operating cam mechanisms. There exist two main forms of follower motions: swinging and sliding movement, and the path of the follower roller towards the cam surface is different in both cases. If this difference is not observed in the production of the cam profile inaccuracies in the transmission

of movement are unavoidable. The same refers to mechanisms where the follower is not provided with a roller but is plate- or mushroom-shaped.

In Figs. 12 to 20 only the cam profiles and forms of curves are shown and the form of follower movement is not considered. Fig. 12 shows a simple closed cam on the surface of a cylinder being usually designated as a cylindrical or drum cam. Fig. 13 shows another form of a cylindrical cam in which the cam profile performs several full turns. In the case of uniform movement, the profile would assume a helical or thread-like shape.

Fig. 14 shows the inverse arrangement, whereby a cylinder is provided with a cog-shaped projection extending over only a portion of the periphery. In this



Figs. 12 to 20.—Different types of cams: simple closed cylindrical or drum cam; cylindrical cam with several turns, thread-type; cog-type curve on a cylinder, swinging movement; cam groove on globe-shaped body; cam groove on globe-shaped body; open cylindrical or end cam; open radial or disc cam; closed or face cam with groove; open cam plate for sliding movement, used, for instance, on automatics.

case the cylinder cam performs only a swinging movement. Figs. 15 and 16 show two spherical or globe cams, the main body being of so-called globoid form, being derived from the rotation of a circle the centre of which does not coincide with the axis of rotation. Fig. 17 is a special open cam on a cylinder or drum, called an end cam. Fig. 18 is an open or periphery cam, whereas Fig. 19 is a face cam or cam with groove.

Fig. 20 represents an open cam, such as is used on automatic screw machines. The Figs. 12 to 16, and Fig. 19, show cams with form constraint, i.e. cams which guide a roller in both directions, and the movement generated is positive. In the case of Figs. 17, 18, and 20, the roller is guided by the cam profile in only one direction, and has to be kept in contact with the profile by means of an external force, say weight or spring; this kind of arrangement is called force closure.

For the production of cams the methods of turning, milling, and grinding are in application. The turning in lathes or special machines is in many cases, for instance camshafts for internal-combustion engines, the most economical method,

and as a matter of fact the oldest method for producing such irregular shapes. The milling of cams by means of end mills can be considered as the most con-

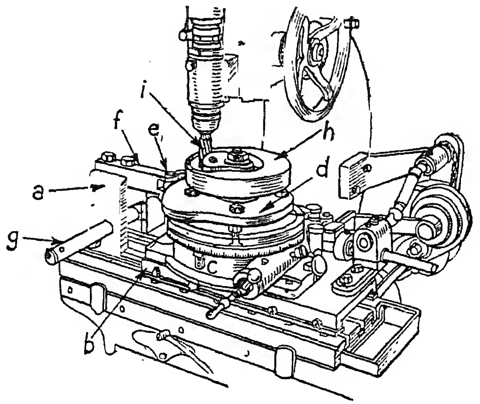


Fig. 21.—Milling a face cam with groove on a vertical milling machine : *a*, base of fixture ; *b*, slide moving on base ; *c*, circular table ; *d*, template (open cam) ; e, tracer roller ; *f*, bracket for holding roller e ; *g*, hand-operated shaft operating rack and pinion drive ; *h*, face cam to be machined ; *i*, end mill.

ventional method, and with this almost all cam profiles can be generated. Together with the profile grinding with small grinding wheels, it is the only method

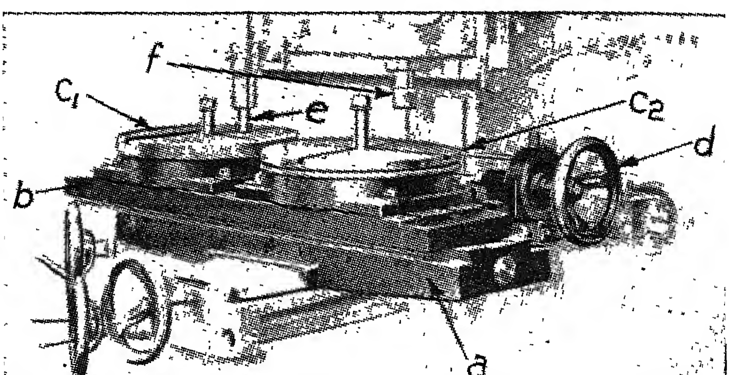


Fig. 22.—Milling fixture with separate tables for template and cam to be machined ; *a*, base of fixture, mounted on machine table ; *b*, slide moving on base ; c_1, circular table carrying the template ; c_2, circular table carrying the workpiece ; *d*, hand-wheel operating worm drives for the simultaneous rotation of the tables ; e, trace roller, fixed on machine column; *f*, milling cutter (end mill).

which leads to the production of grooved curves. In all other cases the grinding is restricted in the same way as the turning to open or external cam profiles,

These remarks already indicate that the selection of the cam form and shape has to be made also with consideration of the best production method, and it is therefore not inappropriate to demand that production possibilities should be considered already in the design. For instance, eccentric cams can be easily machined in the lathe, or even ground, and therefore should be preferred to more complicated profiles.

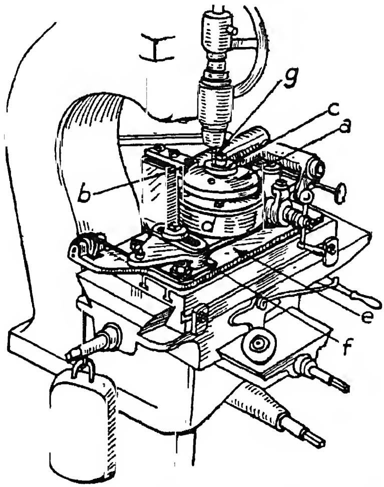


Fig. 23.—Correct milling fixture for producing cams operating swinging levers : a, template (open cam) ; b, tracer roller, mounted on fixed bracket ; c, cam to be machined ; d, circular table mounted on swinging lever ; e, base plate of fixture mounted on machine table ; f, fulcrum (adjustable) of circular table ; g, milling cutter (end mill).

Production of Radial or Face Cams.—Grooved cams and open cams can be produced by the device (Fig. 21) the basis of which is a circular table (*c*) operated by a worm gear. This table is mounted on a slide (*b*). The main body (*a*) of the fixture is clamped to the machine table and contains a bracket which carries on a holder (*f*) the tracer roller (*e*), being held in contact with the template (*d*) by a weight-loaded rope. Template (*d*) is mounted with the cam plate (*h*) on the same vertical mandrel. From this it is obvious that in this case the template can be of the same or, better, larger size than the actual cam profile. Usually the template will be made larger, as, for instance, shown in the illustration, thus increasing the accuracy of production. Shaft (*g*) is provided with a pinion meshing with a rack on the table ; this permits removal of slide (*b*) from the tracer roller. The round table (*c*) can be driven from the milling machine by the usual telescopic feed shaft, or rotated by hand if required.

This method has been changed in Fig. 22 by using two separate circular tables, one carrying the template, the other the cam disc. Both tables have to be rotated with the same speed to obtain conformity between template and cam profile. This fixture is considerably lower than that shown in Fig. 21, being of advantage with regard to stability. As, further, the middle of the table is not obstructed, the template can be made of the same size as the cam disc ; therefore, *accurate workpieces* can be used as templates. If, further, the transmission ratio between template and workpiece is changed, from a single-lobed template cams with several lobes can be derived.

The hitherto described devices produce satisfactory cams, if these are combined with sliding followers, but for the accurate machining of cams operating swinging levers arrangements similar to that in Fig. 23 should be used. Template (*a*) and

cam (*c*) are mounted on the circular table (*d*), mounted on a swinging lever with fulcrum (*f*) in the stationary table (*e*). The tracer roller (*b*) is held on a stationary bracket mounted also on table (*e*). Pressure again is generated by rope and weight. The horizontal distance BC (Fig. 24) has to correspond to the length of the swinging lever, B′C′ in the actual cam mechanism, whereas distance AB, i.e.

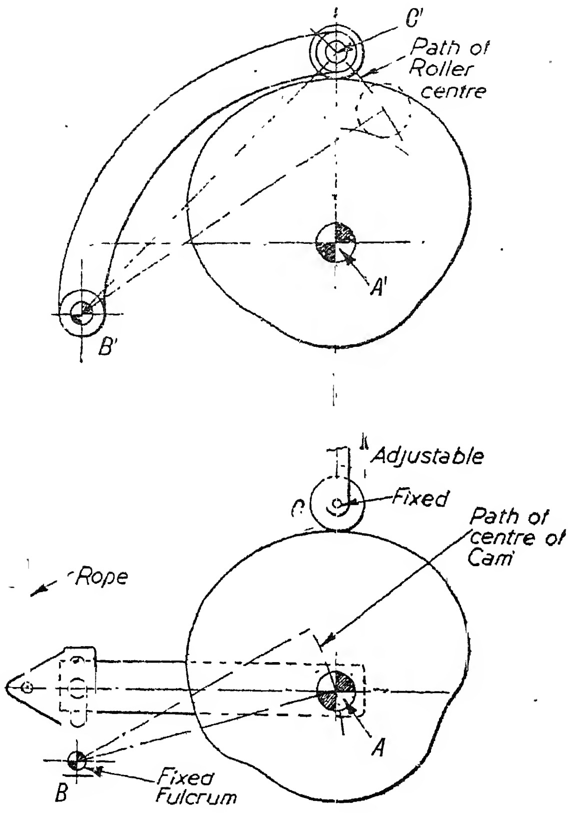


Fig. 24.—Principle of the mechanism: above, cam-milling mechanism; below, actual cam mechanism.

distance between centre of table and fulcrum of (*f*), has to correspond to the distance A′B′ between fulcrum of the swinging lever to the centre of cam disc in the actual mechanism. In the shown device both the distances AB and BC can be changed by means of slots and clamping-screw bolts.

Fig. 25 shows a special milling fixture for the cam on an automatic drilling machine; the main portions of this cam are limited by arcs. The fixture consists

of the base (*a*), the rotating table (*b*) with inbuilt worm gear (*c*) and (*d*), hand-operated, and the slide (*e*). The workpiece (*m*) is placed on pin (*h*) and clamped by a nut. A second pin (*i*) serves for the exact location. This fixture allows accurate arc-shaped cams to be produced by milling; for instance, at first the smaller radius *r*1, followed by radius *r*2. The production of cams with accurate lift is facilitated bv placing gauge blocks between the abutments (*k*) and (*l*).

The main idea for the testing device (Fig. 26) is that not only the cam shape is controlled, but actually the movement of the centre of the cam roller, i.e. the

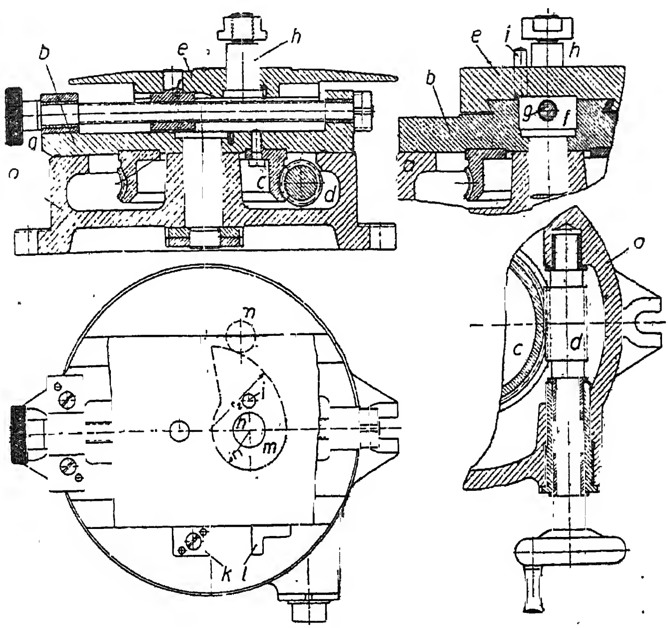


Fig. 25.—Fixture for milling radii on a feed-cam for automatic drilling machines: *a*, base; *b*, rotatable table; *c*, worm-wheel; *d*, worm operated by hand-wheel; *e*, slide mounted on table; *f*, moving nut; *g*, screw spindle; *h*, reception pin for workpiece *m*; *i*, pin for the location of workpiece *m*; *k*, set-edge on *b*; *l*, set-edge on e (between *k* and *l*, gauge blocks are placed to determine the exact lift); *m*, workpiece (open cam); *n*, end mill.

pitch line. This is obviously of far greater importance than the testing of the cam profile itself. The testing device refers to an open cam operating a slide, the direction of which goes through the centre of cam. The device is on principle a circular table operated by a worm gear; the only difference is that this device is of lighter construction. The lift is read on scale (*g*) with a vernier, and the angular position is found on graduations on the outer ring, extending from 0 to 100 in this case.

Machining Cylindrical Cams.—Fig. 27 shows the machining in a lathe of a cylindrical cam with closed cam profile. The workpiece (*d*), together with the master cam (*a*), are fixed in the same mandrel (*e*), rotating between fixed centres and carried by an ordinary dog. On the saddle a bracket (*b*) with a guiding finger is fixed and transmits the movements of the master cam to the cutting tool (*c*).

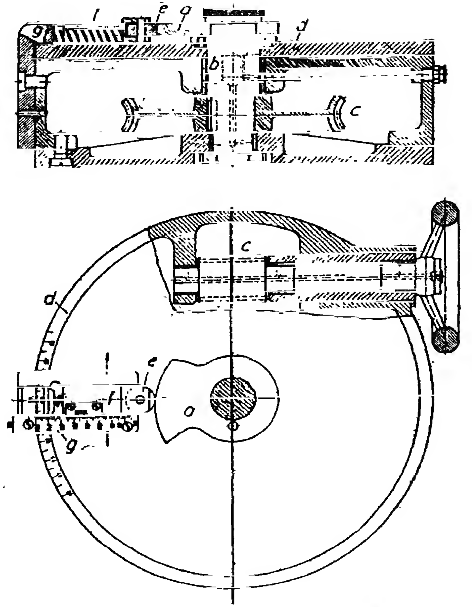


Fig. 26.—Testing device for open cam, testing the pitch-line of cam : *a*, workpiece (open cam) ; *b*, mandrel ; *c*, worm drive operated by hand-wheel ; *d*, upper table with graduation in hundred parts ; *e*, tracer roller ; *f*, slide carrying *e*, under spring pressure, and provided with a vernier ; *g*, guide for *f* with rule.

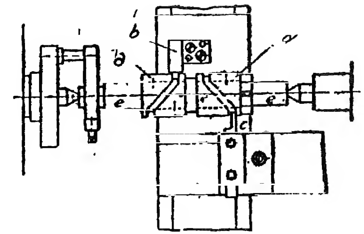


Fig. 27.—Turning of a cylindrical cam in a lathe, according to a template or master cam : *a*, template ; *b*, tracer pin, mounted in bracket on longitudinal slide ; *c*, turning tool ; *d*, workpiece (cylindrical cam) ; *e*, common arbor.

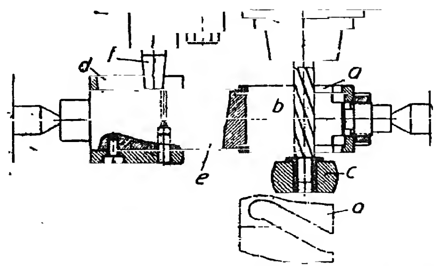


Fig. 28.—Milling of cylindrical cams open on one side : *a*, workpiece (cylindrical cam) ; *b*, end mill ; *c*, support for end mill ; *d*, template ; *e*, common arbor ; *f*, tracer pin.

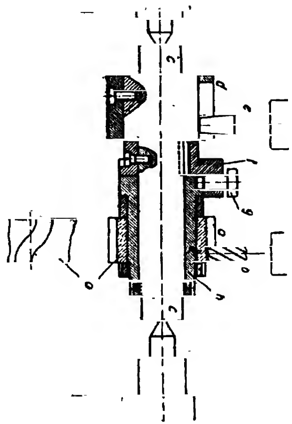


Fig. 29 (Left).—Milling of multiple cylindrical curves according to a template with a single profile : *a*, workpiece ; *b*, end mill ; *c*, mandrel ; *d*, master cam fixed to *c* ; e, tracer pin ; *f*, bracket connected with *c* ; *g*, index screw ; *h*, bush for the reception of *a*, with index holes, loose in mandrel.

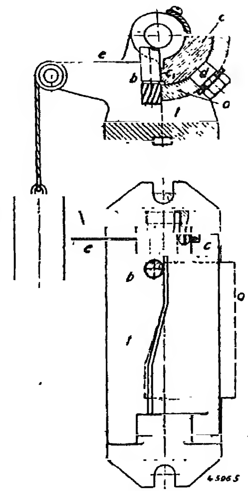
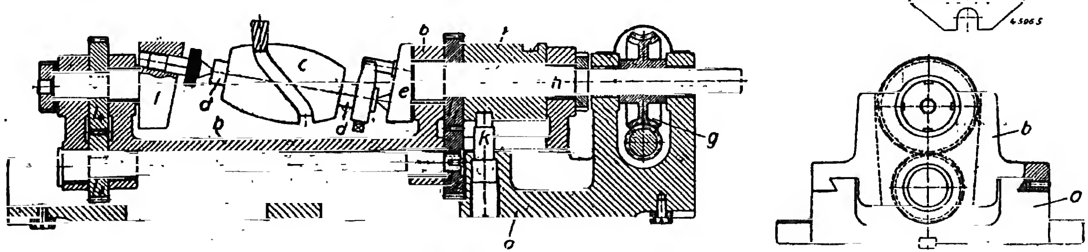


Fig. 30 (Right).—Milling of cam segments : *a*, workpiece ; *b*, end mill with accurately ground shank, serving as tracer pin ; c, cradle to which segment *a* is fixed; c_1, template face ; *d*, two locating pins, with nut and washer, only one shown ; e, rope with weight presses c_1 against *b* ; *f*, body of fixture.

Fig. 31 (Below).—Special attachment for milling a globe-shaped cam : *a*, base plate with slide in horizontal direction ; *b*, upper slide ; *c*, workpiece (globe-shaped cam) ; *d*, mandrel with dog ; e, plate with eccentric centre point and dog driver; *f*, plate with eccentric centre point, slidable in axial direction; *g*, worm drive in base *a*; *h*, shaft with axial slot; *i*, cam template mounted on *h* ; *k*, tracer pin, stationary in base *a* ; l_1 to l_4 gear reductions from e to *f*, ratio *L* to *l*.



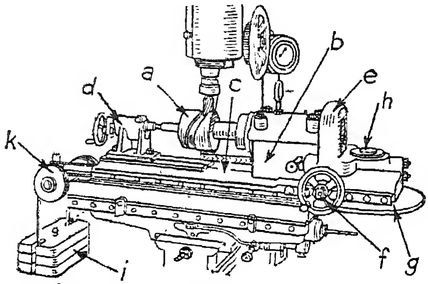


Fig. 32.—Special attachment for producing cylindrical-cams from radial templates: *a*, cylindrical workpiece on mandrel; *b*, headstock of fixture; *c*, base plate of fixture; *d*, tailstock of fixture; *e*, worm-gear built in headstock; *f*, hand-wheel operating worm which drives worm-wheel on headstock and worm-wheel for the spindle of template; worm gear can also be driven from telescopic feed-shaft of the milling machine; *g*, radial template; *h*, vertical spindle of template, driven by worm-wheel; *i*, weights suspended on ropes; *k*, guiding rollers for rope.

A device for the production of open-cam profiles in a cylindrical workpiece on a milling machine is shown in Fig. 28. The cam profile is provided on both sides of the workpiece, and therefore these curved slots can be machined simultaneously by a special milling cutter (*b*), as the common mandrel for template and workpiece is slotted.

In order to obtain high accuracy in the production of several open-cam profiles arranged round the periphery of a cylindrical bush, only one master profile is used and the arbor provided with a simple indexing device (Fig. 29). The workpiece (*a*) is located on a special bush (*h*), situated on mandrel (*c*), and clamped by a grooved nut. The collar of bush (*h*) has several conical holes for fitting the index screw (*g*). The latter is situated in a bracket (*f*) rigidly connected by key and keyways on the mandrel (*c*), on which also the template (*d*), consisting of a cylindrical bush, is mounted.

A special fixture has been developed for the machining of a curved surface on a cylindrical segment (Fig. 30). The U-shaped fixture body (*f*) supports in two outside bearings a cradle (*c*), which forms simultaneously with its front part (*c*1), the template (*a*) guiding the shank of the milling cutter (*b*). The workpiece is placed on two pins (*d*) and fastened by washer and screw; the washer has a cylindrically shaped bottom surface. The contact between workpiece and milling cutter is generated by a rope (*e*) and weight.

A special fixture for the machining of a globoid cam is shown in Fig. 31. It is developed for use on a vertical milling machine, and is operated by hand or mechanically through the worm gear (*g*). The master cam is in this case machined on a cylindrical surface, and the necessary swinging and sliding movements are generated by the copying pin (*k*) situated in the base. The globoid workpiece is placed between centres (*e*) and (*f*), from which the centre (*f*) is adjustable.

Since the templates for drum cams are expensive and produced only with some difficulties, special attachments have been developed which permit the use of face or radial templates to produce cylindrical cams. For the design of these templates or master cams it has only to be remembered that a full rotation of the cylinder corresponds to a full rotation of the disc. Fig. 32 shows such an attachment, which can be placed as a unit on the table of horizontal or vertical milling machines. The cylinder (*a*) to be machined is mounted on a

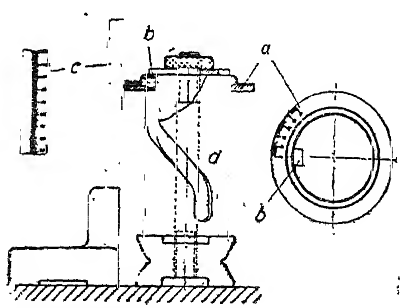


Fig. 33.—Simple testing device for cylindrical cams; *a*, ring slipped over cam, provided with roller and graduations; *b*, steel roller mounted in *a*; *c*, vertical rule; *d*, cylindrical cam to be tested.

mandrel and held between headstock (*b*) and tailstock (*d*). The headstock has an extension taking a vertical spindle (*h*), which carries the face template (*g*), abutting against a roller on the machine table (not visible). The upper slide is loaded by weights (*i*), suspended on ropes guided by rollers (*k*), thus ensuring the necessary contact between template and roller. The connection between horizontal spindle for the cylindrical cam and the vertical spindle for the template is by means of two worm-wheels having a common worm. This can be operated by hand through wheel (*f*) or by the telescopic drive.

Testing of Cylindrical Cams.—Fig. 33 shows a simple testing device for a cylindrical cam. The workpiece is placed on a prismatic block and clamped by a vertical stud bolt and a knurled nut. A vertical scale (*c*) is arranged parallel to the workpiece to indicate the accurate height position. The roller (*b*) sliding in the groove of the cam is attached to a ring (*a*), the outer edge of which is graduated. When sliding the roller along the groove of the fixed cam on scale (*c*) and ring (*a*), each co-ordinated height and angular position of the cam profile can be tested.

A more accurate testing device for cylindrical cams is shown in Fig. 34. A slide (*c*) is guided along the fixture body (*h*). This movement is performed by rack (*e*) and pinion (*f*) operated by lever (*g*). Shaft (*b*) is situated in a double-row ball bearing in slide (*c*) and further in bushes in the main body. A drum with graduation (*m*) is riding on shaft (*l*), but can be clamped to the latter by the clamping device (*n*). Shaft (*l*) is connected with shaft (*b*) by two spur wheels and a pinion, for reversing the direction. A bridge (*i*) is fixed to the main body and has an accurate scale with vernier reading as well as a tracing pin (*o*) acting under spring pressure. Pin (*o*) fits into the groove of the workpiece (*a*), which is fitted on shaft (*b*).

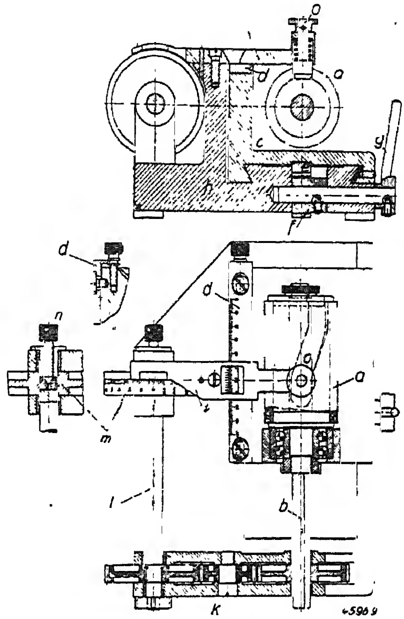
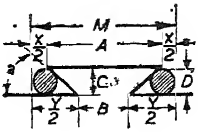
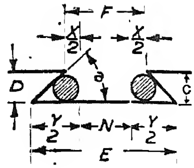


Fig. 34.—Improved testing device for cylindrical cams: *a*, workpiece (cylindrical cam); *b*, mandrel and shaft; *c*, longitudinal slide; *d*, rule adjustable on slide *c*; *e*, rack fixed to slide *c*; *f*, pinion; *g*, hand lever for operation of the slide; *h*, base body of attachment; *i*, bridge connected with *h*, supporting zero-marks and vernier for rules *d* and *m*; *k*, gear-transmission, ratio 1 to 1; *l*, shaft of drum *m*; *m*, drum with graduations, sliding on *l*; *n*, fixing screw for *m*; *o*, tracer pin under spring pressure.

It is important to remember that a roller follower for a cylindrical cam, which works in a groove, should be of conical, not cylindrical, form to avoid friction and to enable it to rotate freely. The roll or follower and the pin upon which it is mounted must, of course, be hardened and ground. In order to avoid flat spots on the follower the surface must rotate truly, the circumference being perfectly concentric with the axis.



External and Internal Dovetails

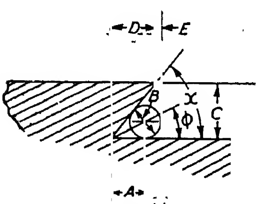


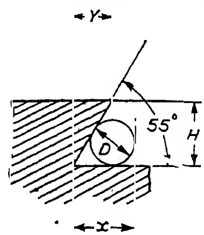
$M = A + X = B + Y$ $\qquad$ $N = E - Y = F - X$

C (in.)	D (in.)	35° X	35° Y	40° X	40° Y	45° X	45° Y	50° X	50° Y	55° X	55° Y	60° X	60° Y
0·3750	0·2500	*—0·0282	1·0429	0·0430	0·9369	0·1035	0·8535	0·1568	0·7861	0·2050	0·7302	0·2500	0·6830
0·4375	0·3750	0·3148	1·5644	0·3625	1·4053	0·4053	1·2803	0·4450	1·1792	0·4827	1·0954	0·5193	1·0245
0·5000	0·3750	0·1363	1·5644	0·2135	1·4053	0·2803	1·2803	0·3401	1·1792	0·3952	1·0954	0·4471	1·0245
0·5625	0·5000	0·4791	2·0858	0·5330	1·8738	0·5820	1·7070	0·6282	1·5722	0·6727	1·4604	0·7165	1·3660
0·6250	0·5000	0·3006	2·0858	0·3840	1·8738	0·4570	1·7070	0·5233	1·5722	0·5851	1·4604	0·6443	1·3660
0·7500	0·5000	*—0·0564	2·0858	0·0861	1·8738	0·2070	1·7070	0·3135	1·5722	0·4101	1·4604	0·5000	1·3660
0·8750	0·7500	0·6294	3·1287	0·7249	2·8106	0·8106	2·5606	0·8900	2·3584	0·9654	2·1908	1·0386	2·0490
1·0000	0·7500	0·2724	3·1287	0·4270	2·8106	0·5606	2·5606	0·6892	2·3584	0·7904	2·1908	0·8943	2·0490
1·1250	0·7500	*—0·0846	3·1287	0·1290	2·8106	0·3106	2·5606	0·4704	2·3584	0·6153	2·1908	0·7500	2·0490
1·2500	0·7500	—	—	—	—	0·0606	2·5606	0·2606	2·3584	0·4403	2·1908	0·6056	2·0490

$Y = D \cot \frac{a}{2} + D$ $\qquad$ $X = Y - 2C \cot a$

* In practice these vees are measurable using the plugs indicated, since the sharp corners of the vee must necessarily be flatted.

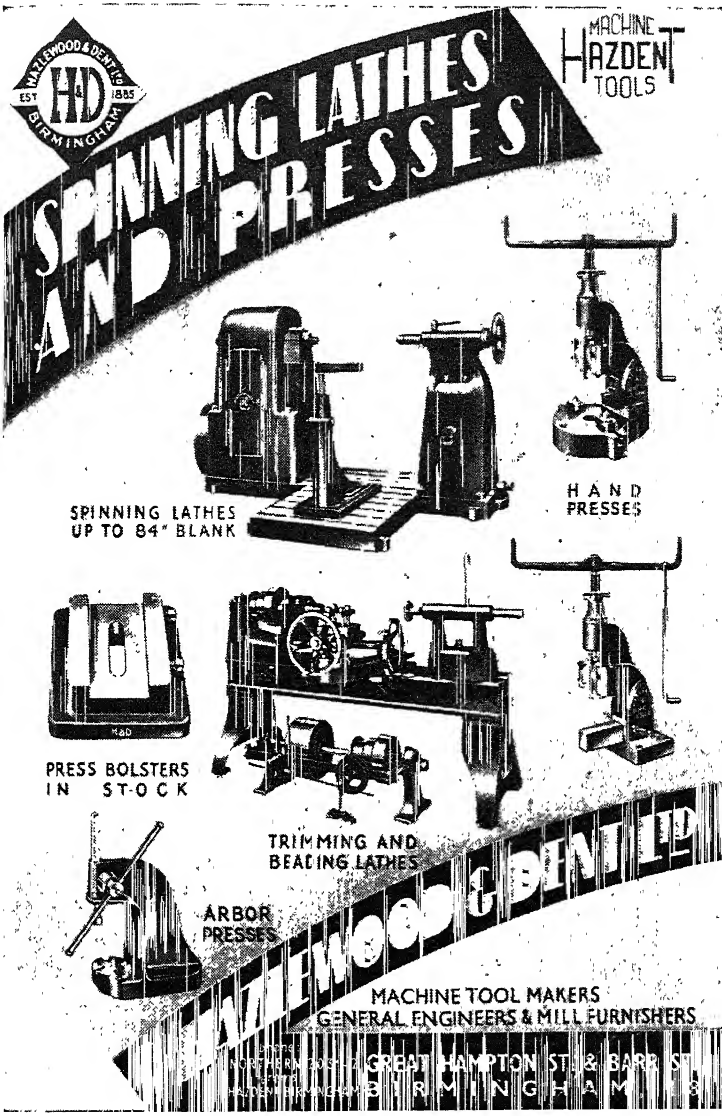




D (in.)	C (in.)	D (in.)	C (in.)	H (in.)	Y (in.)
1/16	0·09128	9/16	0·82153	3/8	0·262575
1/8	0·18256	5/8	0·91281	1/2	0·35010
3/16	0·22696	11/16	1·00409	5/8	0·43762
1/4	0·36512	3/4	1·09537	3/4	0·52515
5/16	0·45640	13/16	1·18665	7/8	0·61268
3/8	0·54768	7/8	1·27793	1	0·70021
7/16	0·63896	15/16	1·36921	1 1/4	0·87524
1/2	0·73025	1	1·46050	1 1/2	1·05031
				1 3/4	1·22537
				2	1·40042

$A = \cot \times \Phi \frac{B}{2}$ $\qquad$ $D = \cot \Phi \times C$ $\qquad$ $E = A + \frac{B}{2} = D$

Cot of 55° = 0·70021 in. $\qquad$ Cot of $27\frac{1}{2}°$ = 1·9210 in.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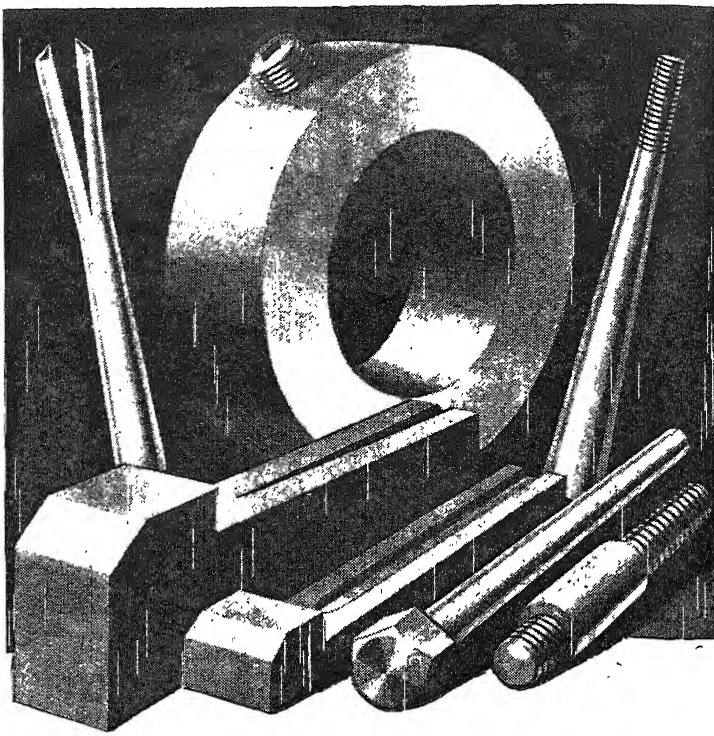


KEYS AND KEYWAYS

The Tables given in this section are based on B.S. Specification No. 46/1929, which replaces No. 46/1909 and No. 46/1924, and are published by permission of the British Standards Institution.

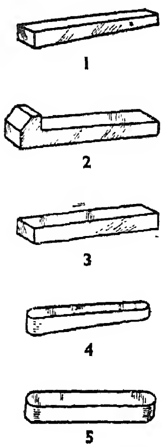


Fig 1.—Types of key.

Types of Key.—Fig. 1 illustrates five main types of key—1, the plain taper key: 2, gib-head key; 3, plain parallel key; 4, round-ended taper key: and 5, the round-headed parallel key.

Fig. 2 illustrates various types of keyway; Figs. 3 to 14 various types of keying, and Figs. 15 to 18 splines and serrations.

Fitting.—When the key bears hard on the top and bottom of the keyways, and lightly on the sides, it is known as top and bottom fitting. When the key bears hard on the sides and lightly or not at all on top and bottom, that is known as side fitting. (See Figs. 19 and 20.)

Coned and Keyed Shaft-ends.—The standard taper is 1 in 10 on diameter, and the key is parallel to the side of the cone. The size of the key is given in Tables 1 and 2, and corresponds with the shaft diameter equivalent to the larger end of the cone.

Length of Key.—The length of the key depends on the length of the box, but it is desirable that the key should not be shorter than 1½ times the diameter of the shaft at the large end of the cone. (See Fig. 21.)

Rectangular and Square Parallel Keys.—The depth of immersion of the key given in Table 1, columns 6 and 7, and Table 2, columns 5 and 6, has been calculated so as to give approximately 50 per cent. immersion at the sides. (See Figs. 22 and 23.)

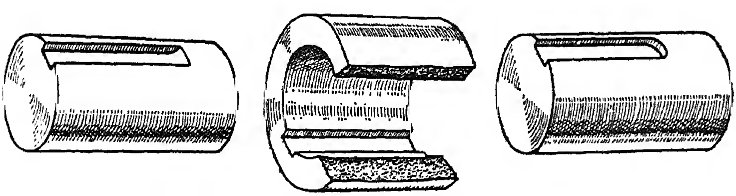


Fig. 2.—Various types of keyway.

Rectangular and Square Taper Keys.—The depth of immersion of the key on the centre line in the shaft (Table 3, column 9; Table 4, column 8; Table 5, column 13; and Table 6, column 12) is the same as that for the corresponding side of parallel key.

The depth of the key on the centre line on the hub given in Table 3, column 10; Table 4, column 9; Table 5, column 14; and Table 6, column 13, is measured at the face of the hub and at the deep end of the keyway. The slight difference in the dimension in Table 3, column 10, and Table 4, column 9, as compared with the corresponding columns in Tables 1 and 2, for parallel keys, is necessary to enable the same key bars to be used for both parallel and plain taper keys.

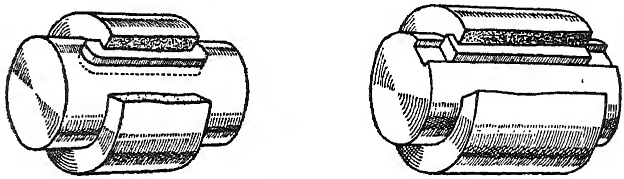


Fig. 3.—Sunk keys, partly in hub, and partly in shaft.

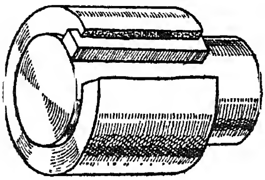


Fig. 4.—Hollow saddle key.

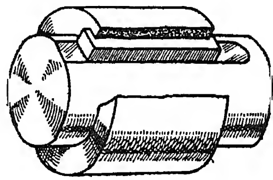


Fig. 5.—Flat saddle key.

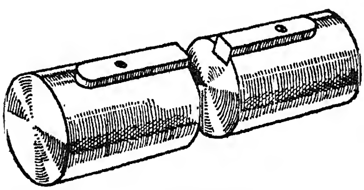


Fig. 6.—Feather key.

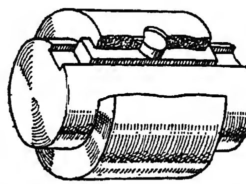


Fig. 7.—Peg feather key.

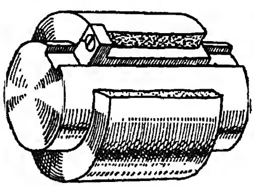


Fig. 8.—Single-head feather key.

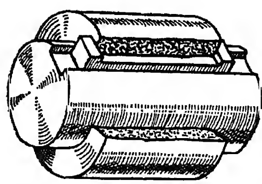


Fig. 9.—Double-head feather key.

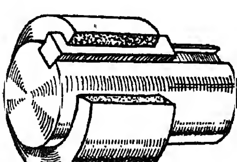


Fig. 10.—Dovetail key.

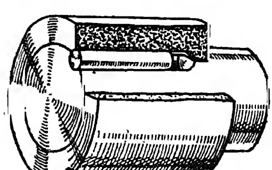


Fig. 11.—Round key.

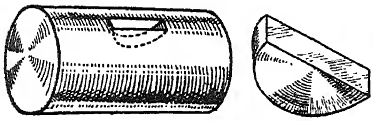


Fig. 12.—Woodruff key and keyway.

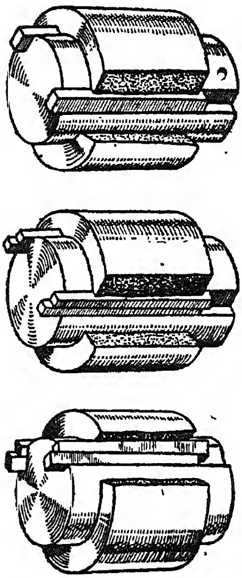


Fig. 13.—Tangential keying.

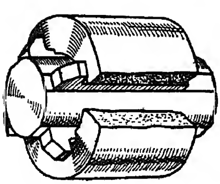


Fig. 14.—Stake keying.

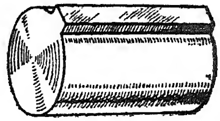


Fig. 15.—Spline.

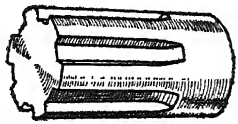


Fig. 16.—Spline shaft.

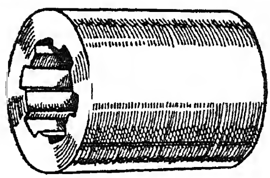


Fig. 17.—Spline hub.

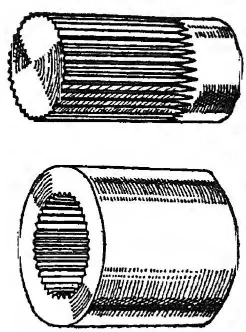


Fig. 18.—Serrated shaft and hub.

The same difference occurs in Table 5, column 14, and Table 6, column 13, in order that the keyway depths may be the same as those for the plain taper keys.

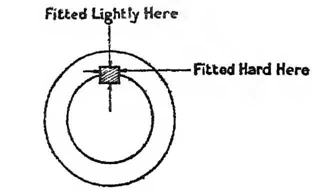


Fig. 19.—Top and bottom fitting.

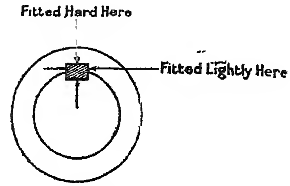


Fig. 20.—Side fitting.

Fitting Rectangular and Square Parallel Keys.—The tolerances given in Tables 1 and 2 provide an allowance (interference) for fitting at the sides, and a clearance at the top and bottom of the key.

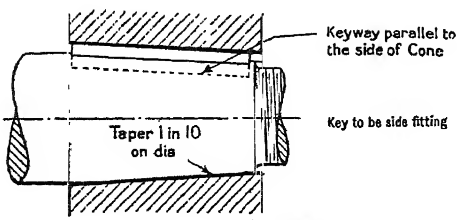


Fig. 21.—Standard taper.

Fitting Rectangular and Square Taper Keys.—The tolerances given in Tables 3 to 6 provide an allowance for fitting at the top and bottom, as well as at the sides.

Taper Keys.—The standard taper is 1 in 100. The nominal thickness of a plain taper key (Tables 3 and 4) is measured at the large end. The nominal thickness of a gib-head taper key (Tables 5 and 6) is measured at the point where the radius of the gib-head terminates.

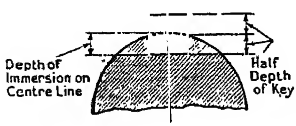


Fig. 22.—Depth of immersion of B.S. square parallel key.

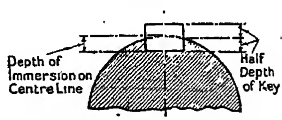


Fig. 23.—Depth of immersion of B.S. rectangular parallel key.

Rounding of Keys and Keyways.—It is recommended that in cases where shafts are to be highly stressed or subjected to alternating stresses, or variable

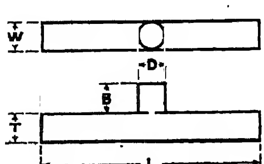


Fig. 24.—T keys.

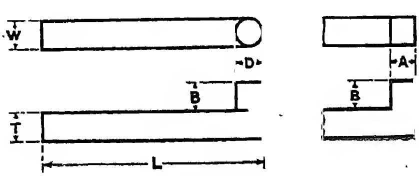


Fig. 25.—L keys.

loads, the corners of the keyways be rounded to approximately one-fifth of their depth, the edges of the keys being rounded to correspond.

Ends of Keys.—The ends of keys shall be cut off square unless otherwise specified.

Peg Feather Keys (see Table 7).—Where it is desired to rivet the peg of the key to the sliding member or otherwise, a suitable increase in the length of the peg should be provided. Feather keys should be made with a minus tolerance to suit the keyways shown in Table 2.

Figs. 24 and 25 show T keys and L keys respectively.

Tangential Keys (see Tables 9 and 10).—The length of these keys is determined by the length of the whole to be keyed on the shaft. The extra length for driving should not be less than the width of the pair of keys.

In this form of key gib-heads should be used when the keys can only be driven from one end. If both ends of the key are accessible, gib-heads are not necessary. When gib-heads are used, the length of the keys should be measured to the inside of the heads. In type A tangential key (Fig. 26), the width of the two keys W is three-tenths (0·3) of the diameter of the shaft, in which case the thickness of the key becomes one-tenth (0·1) of the diameter of the shaft.

Type B tangential key as shown in Fig. 27.

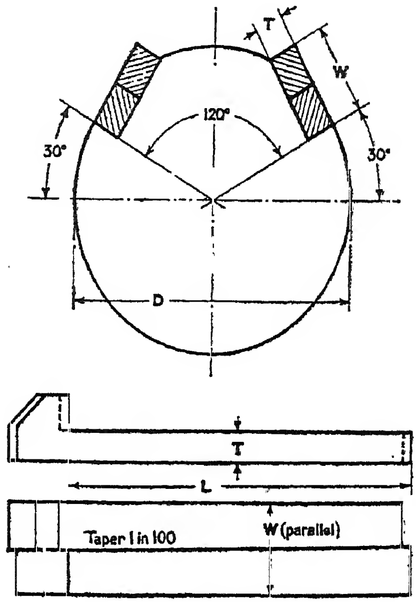


Fig. 26.—Tangential keys, type A.

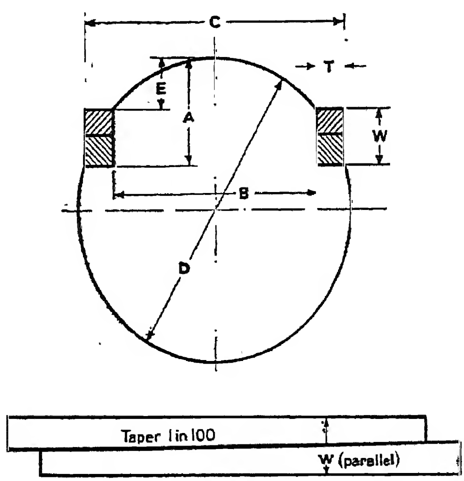


Fig. 27.—Tangential keys, type B.

TABLE 1

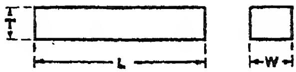
BRITISH STANDARD

RECTANGULAR PARALLEL KEYS, KEYWAYS AND KEY BARS

Designation	*Shaft Diameters*		*Key*		*Depth of Immersion of Key on Centre Line (Nominal)*		
	Over	*Up to and including*	*Nominal and Minimum Width* **W**	*Nominal and Minimum Thickness* **T**	*In Shaft*	*In Hub*	*Max. Width in Shaft and Hub*
B.S.K. 3/32 R. †	3/16	1/4	3/32 *(0·09375)*	3/32 *(0·09375)*	0·0574	0·0364	0·0938
B.S.K. 1/8 R. †	1/4	3/8	1/8 *(0·125)*	1/8 *(0·125)*	0·0756	0·0494	0·1250
B.S.K. 5/32 R. †	3/8	1/2	5/32 *(0·15625)*	5/32 *(0·15625)*	0·0925	0·0638	0·1563
B.S.K. 3/16 R.	1/2	3/4	3/16 *(0·1875)*	5/32 *(0·15625)*	0·0925	0·0638	0·1875
B.S.K. 1/4 R.	3/4	1	1/4 *(0·25)*	3/16 *(0·1875)*	0·1120	0·0755	0·2500
B.S.K. 5/16 R.	1	1 1/4	5/16 *(0·3125)*	7/32 *(0·21875)*	0·1315	0·0873	0·3125
B.S.K. 3/8 R.	1 1/4	1 1/2	3/8 *(0·375)*	1/4 *(0·25)*	0·1511	0·0989	0·3750
B.S.K. 7/16 R.	1 1/2	1 3/4	7/16 *(0·4375)*	9/32 *(0·28125)*	0·1706	0·1107	0·4375
B.S.K. 1/2 R.	1 3/4	2	1/2 *(0·5)*	11/32 *(0·34375)*	0·2058	0·1380	0·5000
B.S.K. 9/16 R.	2	2 1/4	9/16 *(0·5625)*	3/8 *(0·375)*	0·2254	0·1496	0·5625
B.S.K. 5/8 R.	2 1/4	2 1/2	5/8 *(0·625)*	13/32 *(0·40625)*	0 2450	0·1613	0·6250
B.S.K. 11/16 R.	2 1/2	2 3/4	11/16 *(0·6875)*	15/32 *(0·46875)*	0·2802	0·1886	0·6875
B.S.K. 3/4 R.	2 3/4	3	3/4 *(0·75)*	1/2 *(0·5)*	0·2998	0·2002	0·7500
B.S.K. 7/8 R.	3	3 1/2	7/8 *(0·875)*	5/8 *(0·625)*	0·3726	0·2524	0·8750
B.S.K. 1 R.	3 1/2	4	1	11/16 *(0·6875)*	0·4117	0·2758	1·0000
B.S.K. 1 1/8 R.	4	4 1/2	1 1/8 *(1·125)*	3/4 *(0·75)*	0·4508	0·2992	1·1250
B.S.K. 1 1/4 R.	4 1/2	5	1 1/4 *(1·25)*	13/16 *(0·8125)*	0·4900	0·3225	1·2500
B.S.K. 1 3/8 R.	5	5 1/2	1 3/8 *(1·375)*	15/16 *(0·9375)*	0·5604	0·3771	1·3750
B.S.K. 1 1/2 R.	5 1/2	6	1 1/2 *(1·5)*	1	0·5996	0·4004	1·5000
B.S.K. 1 5/8 R.	6	6 1/2	1 5/8 *(1·625)*	1 1/16 *(1·0625)*	0·6388	0·4237	1·6250
B.S.K. 1 3/4 R.	6 1/2	7	1 3/4 *(1.75)*	1 3/16 *(1·1875)*	0·7092	0·4783	1·7500
B.S.K. 1 7/8 R.	7	7 1/2	1 7/8 *(1·875)*	1 1/4 *(1·25)*	0·7483	0·5017	1·8750
B.S.K. 2 R.	7 1/2	8	2	1 3/8 *(1·375)*	0·8187	0·5563	2·0000
B.S.K. 2 1/4 R.	8	9	2 1/4 *(2·25)*	1 1/2 *(1·5)*	0·9016	0·5984	2·2500
B.S.K. 2 1/2 R.	9	10	2 1/2 *(2·5)*	1 5/8 *(1·625)*	0·9799	0·6451	2·5000
B.S.K. 2 3/4 R.	10	11	2 3/4 *(2·75)*	1 7/8 *(1·875)*	1·1208	0·7542	2·7500
B.S.K. 3	11	12	3	2	1·1991	0·8009	3·0000

* Where Key Bars are required to produce keys for which a fitting allowance is not desired, they specified in col. 16.

† These keys are identical with the B.S. Square



(All Dimensions are in Inches)

Keyway		*Finished Key Bar* (See footnote)*		*Tolerances*				*Standard Lengths L*		
Minimum Depth on Centre Line				*On Key*	*On Keyway*		*On Key Bar*			
In Shaft	*In Hub*	*Min. Width*	*Min. Thickness*	*Width and Thickness −·0000*	*Width +·0000*	*Depth −·0000*	*Width and Thickness −·0000*	*Minimum*	*Increasing by*	*Maximum*
0·0584	0·0374	0·0978	0·0978	+·0010	−·0010	+·0010	+·0020	3/8	1/8	3/4
0·0766	0·0504	0·1290	0·1290	+·0010	−·0010	+·0010	+·0020	1/2	1/8	1
0·0935	0·0648	0 1603	0·1603	+·0010	−·0010	+·0010	+·0020	5/8	1/8	1 1/4
0·0935	0·0648	0·1915	0·1603	+·0010	−·0010	+·0010	+·0020	3/4	1/4	1 1/2
0·1130	0·0765	0·2540	0·1915	+·0010	−·0010	+·0010	+·0020	1	1/4	2
0·1325	0·0883	0·3165	0·2228	+·0010	−·0010	+·0010	+·0020	1 1/4	1/4	2 1/2
0·1521	0·0999	0·3790	0·2540	+·0010	−·0010	+·0010	+·0020	1 1/2	1/4	3
0·1721	0·1122	0·4425	0·2863	+·0015	−·0015	+·0010	+·0020	1 3/4	1/4	3 1/2
0·2073	0·1395	0·5050	0·3488	+·0015	−·0015	+·0010	+·0020	2	1/2	4
0·2269	0·1511	0·5675	0·3800	+·0015	−·0015	+·0010	+·0020	2 1/2	1/2	5
0·2465	0·1628	0·6300	0·4113	+·0015	−·0015	+·0010	+·0020	2 1/2	1/2	5
0·2822	0·1906	0·6945	0·4758	+·0020	−·0020	+·0015	+·0030	3	1/2	6
0·3018	0·2022	0·7570	0·5070	+·0020	−·0020	+·0015	+·0030	3	1/2	6
0·3746	0·2544	0·8820	0·6320	+·0020	−·0020	+·0015	+·0030	3 1/2	1/2	7
0·4137	0·2778	1·0070	0·6945	+·0020	−·0020	+·0015	+·0030	4	1	8
0·4528	0·3012	1·1320	0·7570	+·0020	−·0020	+·0015	+·0030	5	1	10
0·4920	0·3245	1·2570	0·8195	+·0020	−·0020	+·0015	+·0030	5	1	10
0·5629	0·3796	1·3830	0·9455	+·0025	−·0025	+·0015	+·0040	6	1	12
0·6021	0·4029	1·5080	1·0080	+·0025	−·0025	+·0015	+·0040	6	1	12
0·6413	0·4262	1·6330	1·0705	+·0025	−·0025	+·0015	+·0040	7	1	14
0·7117	0·4808	1·7580	1·1955	+·0025	−·0025	+·0015	+·0040	7	1	14
0·7513	0·5047	1·8850	1·2600	+·0030	−·0030	+·0020	+·0040	8	1	16
0·8217	0·5593	2·0100	1·3850	+·0030	−·0030	+·0020	+·0040	8	2	16
0·9046	0·6014	2·2600	1·5100	+·0030	−·0030	+·0020	+·0040	10	2	20
0·9829	0·6481	2·5100	1·6350	+·0030	−·0030	+·0020	+·0040	10	2	20
1·1248	0·7582	2·7620	1·8870	+·0040	−·0040	+·0020	+·0050	12	2	24
1·2031	0·8049	3·0120	2·0120	+·0040	−·0040	+·0020	+·0050	12	2	24

can be obtained to the nominal width and thickness of the keys with the plus tolerances Parallel Keys of the corresponding sizes (Table 2).

Table 2

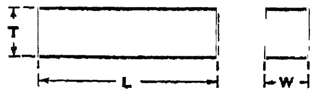
British Standard

Square Parallel Keys, Keyways and Key Bars

Designation	Shaft Diameters: Over	Shaft Diameters: Up to and including	Key: Nominal and Minimum Width and Thickness W × T	Depth of Immersion of Key on Centre Line (Nominal): In Shaft	Depth of Immersion of Key on Centre Line (Nominal): In Hub	Max. Width in Shaft and Hub
B.S.K. 3/32 S.	3/16	1/4	3/32 (0·09375)	0·0574	0·0364	0·0938
B.S.K. 1/8 S.	1/4	3/8	1/8 (0·125)	0·0756	0·0494	0·1250
B.S.K. 5/32 S.	3/8	1/2	5/32 (0·15625)	0·0925	0·0638	0·1563
B.S.K. 3/16 S.	1/2	3/4	3/16 (0·1875)	0·1081	0·0794	0·1875
B.S.K. 1/4 S.	3/4	1	1/4 (0·25)	0·1433	0·1067	0·2500
B.S.K. 5/16 S.	1	1 1/4	5/16 (0·3125)	0·1784	0·1341	0·3125
B.S.K. 3/8 S.	1 1/4	1 1/2	3/8 (0·375)	0·2136	0·1614	0·3750
B.S.K. 7/16 S.	1 1/2	1 3/4	7/16 (0·4375)	0·2487	0·1888	0·4375
B.S.K. 1/2 S.	1 3/4	2	1/2 (0·5)	0·2838	0·2162	0·5000
B.S.K. 9/16 S.	2	2 1/4	9/16 (0·5625)	0·3192	0·2433	0·5625
B.S.K. 5/8 S.	2 1/4	2 1/2	5/8 (0·625)	0·3544	0·2706	0·6250
B.S.K. 11/16 S.	2 1/2	2 3/4	11/16 (0·6875)	0·3896	0·2979	0·6875
B.S.K. 3/4 S.	2 3/4	3	3/4 (0·75)	0·4248	0·3252	0·7500
B.S.K. 7/8 S.	3	3 1/2	7/8 (0·875)	0·4976	0·3774	0·8750
B.S.K. 1 S.	3 1/2	4	1	0·5680	0·4320	1·0000
B.S.K. 1 1/8 S.	4	4 1/2	1 1/8 (1·125)	0·6383	0·4867	1·1250
B.S.K. 1 1/4 S.	4 1/2	5	1 1/4 (1·25)	0·7088	0·5412	1·2500
B.S.K. 1 3/8 S.	5	5 1/2	1 3/8 (1·375)	0·7792	0·5958	1·3750
B.S.K. 1 1/2 S.	5 1/2	6	1 1/2 (1·5)	0·8496	0·6504	1·5000
B.S.K. 1 5/8 S.	6	6 1/2	1 5/8 (1·625)	0·9201	0·7049	1·6250
B.S.K. 1 3/4 S.	6 1/2	7	1 3/4 (1.75)	0·9905	0·7595	1·7500
B.S.K. 1 7/8 S.	7	7 1/2	1 7/8 (1·875)	1·0608	0·8142	1·8750
B.S.K. 2 S.	7 1/2	8	2	1·1312	0·8688	2·0000
B.S.K. 2 1/4 S.	8	9	2 1/4 (2·25)	1·2766	0·9734	2·2500
B.S.K. 2 1/2 S.	9	10	2 1/2 (2·5)	1·4174	1·0826	2·5000
B.S.K. 2 3/4 S.	10	11	2 3/4 (2·75)	1·5583	1·1917	2·7500
B.S.K. 3 S.	11	12	3	1·6991	1·3009	3·0000

* Where Key Bars are required to produce keys for which a fitting allowance is not tolerances

Note: Standard Keys for Arbors and Keyways for Milling Cutters shall be in accordance



(All Dimensions are in Inches)

Keyway		Finished Key Bar* (See footnote)	Tolerances				Standard Lengths L		
Min Depth on Centre Line		Min. Width and Thickness	On Key	On Keyway		On Key Bar	Minimum	Increasing by	Maximum
In Shaft	In Hub		Width and Thickness −·0000	Width +·0000	Depth −·0000	Width and Thickness −·0000			
0·0584	0·0374	0·0978	+·0010	−·0010	+·0010	+·0020	3/8	1/8	3/4
0·0766	0·0504	0·1290	+·0010	−·0010	+·0010	+·0020	1/2	1/8	1
0·0935	0·0648	0·1603	+·0010	−·0010	+·0010	+·0020	5/8	1/8	1 1/4
0·1091	0·0804	0·1915	+·0010	−·0010	+·0010	+·0020	3/4	1/4	1 1/2
0·1443	0·1077	0·2540	+·0010	−·0010	+·0010	+·0020	1	1/4	2
0·1794	0·1351	0·3165	+·0010	−·0010	+·0010	+·0020	1 1/4	1/4	2 1/2
0·2146	0·1624	0·3790	+·0010	−·0010	+·0010	+·0020	1 1/2	1/4	3
0·2502	0·1903	0·4425	+·0015	−·0015	+·0010	+·0020	1 3/4	1/4	3 1/2
0·2853	0·2177	0·5050	+·0015	−·0015	+·0010	+·0020	2	1/4	4
0·3207	0·2448	0·5675	+·0015	−·0015	+·0010	+·0020	2 1/2	1/2	5
0·3559	0·2721	0·6300	+·0015	−·0015	+·0010	+·0020	2 1/2	1/2	5
0·3916	0·2999	0·6945	+·0020	−·0020	+·0015	+·0030	3	1/2	6
0·4268	0·3272	0·7570	+·0020	−·0020	+·0015	+·0030	3	1/2	6
0·4996	0·3794	0·8820	+·0020	−·0020	+·0015	+·0030	3 1/2	1/2	7
0·5700	0·4340	1·0070	+·0020	−·0020	+·0015	+·0030	4	1	8
0·6403	0·4887	1·1320	+·0020	−·0020	+·0015	+·0030	5	1	10
0·7108	0·5432	1·2570	+·0020	−·0020	+·0015	+·0030	5	1	10
0·7817	0·5983	1·3830	+·0025	−·0025	+·0015	+·0040	6	1	12
0·8521	0·6529	1·5080	+·0025	−·0025	+·0015	+·0040	6	1	12
0·9226	0·7074	1·6630	+·0025	−·0025	+·0015	+·0040	7	1	14
0·9930	0·7620	1·7580	+·0025	−·0025	+·0015	+·0040	7	1	14
1·0638	0·8172	1·8850	+·0030	−·0030	+·0020	+·0040	8	1	16
1·1342	0·8718	2·0100	+·0030	−·0030	+·0020	+·0040	8	2	16
1·2796	0·9764	2·2600	+·0030	−·0030	+·0020	+·0040	10	2	20
1·4204	1·0856	2·5100	+·0030	−·0030	+·0020	+·0040	10	2	20
1·5623	1·1957	2·7620	+·0040	−·0040	+·0020	+·0040	12	2	24
1·7031	1·3049	3·0120	+·0040	−·0040	+·0020	+·0050	12	2	24

desired, they can be obtained to the nominal width and thickness of the keys, with the plus specified.

with Tables III and IV of B.S. Specification No. 122—Milling Cutters and Reamers.

TABLE 3

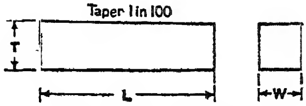
BRITISH STANDARD

PLAIN RECTANGULAR TAPER KEYS, KEYWAYS AND KEY BARS

Designation	*Shaft Diameters*		*Key*				
	Over	*Up to and including*	*Nominal Size*		*Min. Width* W	*Min. Thickness at Large End* T	*Max. Width in Shaft and Hub*
			Width	*Thickness*			
B.S.K. 3/32 P.R.T.†	3/16	1/4	3/32 *(0·09375)*	3/32 *(0·09375)*	0·0938	0·097	0·0938
B.S.K. 1/8 P.R.T.†	1/4	3/8	1/8 *(0·125)*	1/8 *(0·125)*	0·1250	0·129	0·1250
B.S.K. 5/32 P.R.T.†	3/8	1/2	5/32 *(0·15625)*	5/32 *(0·15625)*	0 1563	0·160	0·1563
B.S.K. 3/16 P.R.T.	1/2	3/4	3/16 *(0·1875)*	5/32 *(0·15625)*	0·1875	0·160	0·1875
B.S.K. 1/4 P.R.T.	3/4	1	1/4 *(0·25)*	3/16 *(0·1875)*	0·2500	0·191	0·2500
B.S.K. 5/16 P.R.T.	1	1 1/4	5/16 *(0·3125)*	7/32 *(0·21875)*	0·3125	0·222	0·3125
B.S.K. 3/8 P.R.T.	1 1/4	1 1/2	3/8 *(0·375)*	1/4 *(0·25)*	0·3750	0·254	0·3750
B.S.K. 7/16 P.R.T.	1 1/2	1 3/4	7/16 *(0·4375)*	9/32 *(0·28125)*	0·4375	0·286	0·4375
B.S.K. 1/2 P.R.T.	1 3/4	2	1/2 *(0·5)*	11/32 *(0·34375)*	0·5000	0·348	0·5000
B.S.K. 9/16 P.R.T	2	2 1/4	9/16 *(0·5625)*	3/8 *(0·375)*	0·5625	0·380	0·5625
B.S.K. 5/8 P.R.T.	2 1/4	2 1/2	5/8 *(0·625)*	13/32 *(0·40625)*	0·6250	0·411	0·6250
B.S.K. 11/16 P.R.T.	2 1/2	2 3/4	11/16 *(0·6875)*	15/32 *(0·46875)**	0·6875	0·475	0·6875
B.S.K. 3/4 P.R.T.	2 3/4	3	3/4 *(0·75)*	1/2 *(0·5)*	0·7500	0·507	0·7500
B.S.K. 7/8 P.R.T.	3	3 1/2	7/8 *(0·875)*	5/8 *(0·625)*	0·8750	0·632	0·8750
B.S.K. 1 P.R.T.	3 1/2	4	1	11/16 *(0·6875)*	1·0000	0·694	1·0000
B.S.K. 1 1/8 P.R.T.	4	4 1/2	1 1/8 *(1·125)*	3/4 *(0·75)*	1·1250	0·757	1·1250
B.S.K. 1 1/4 P.R.T.	4 1/2	5	1 1/4 *(1·25)*	13/16 *(0·8125)*	1·2500	0·819	1·2500
B.S.K. 1 3/8 P.R.T.	5	5 1/2	1 3/8 *(1·375)*	15/16 *(0·9375)*	1·3750	0·945	1·3750
B.S.K. 1 1/2 P.R.T.	5 1/2	6	1 1/2 *(1·5)*	1	1·5000	1·008	1·5000
B.S.K. 1 5/8 P.R.T.	6	6 1/2	1 5/8 *(1·625)*	1 1/16 *(1·0625)*	1·6250	1·070	1·6250
B.S.K. 1 3/4 P.R.T.	6 1/2	7	1 3/4 *(1·75)*	1 3/16 *(1·1875)*	1·7500	1·195	1·7500
B.S.K. 1 7/8 P.R.T.	7	7 1/2	1 7/8 *(1·875)*	1 1/4 *(1·25)*	1·8750	1·260	1·8750
B.S.K. 2 P.R.T.	7 1/2	8	2	1 3/8 *(1·375)*	2·0000	1·385	2·0000
B.S.K. 2 1/4 P.R.T.	8	9	2 1/4 *(2·25)*	1 1/2 *(1·5)*	2·2500	1·510	2·2500
B.S.K. 2 1/2 P.R.T.	9	10	2 1/2 *(2·5)*	1 5/8 *(1·625)*	2·5000	1·635	2·5000
B.S.K. 2 3/4 P.R.T.	10	11	2 3/4 *(2·75)*	1 7/8 *(1·875)*	2·7500	1·887	2·7500
B.S.K. 3 P.R.T.	11	12	3	2	3·0000	2·012	3·0000

* Where Key Bars are required to produce keys for which a fitting allowance is not tolerances

† These keys are identical with the B.S. Plain



(All Dimensions are in Inches)

Keyway: Minimum Depth on Centre Line: In Shaft	Keyway: Minimum Depth on Centre Line: In Hub at Deep End	Finished Key Bar* (See footnote): Min. Width	Finished Key Bar* (See footnote): Min. Thickness	Tolerances: On Key: Width −·0000	Tolerances: On Key: Thickness −·0000	Tolerances: On Keyway: Width +·0000	Tolerances: On Keyway: Depth −·0000	Tolerances: On Key Bar: Width & Thickness −·0000	Standard Lengths L: Min.	Standard Lengths L: Increasing by	Standard Lengths L: Max.
0·0584	0·0354	0·0978	0·0978	+·0010	+·0020	−·0010	+·0010	+·0020	3/8	1/8	3/4
0·0766	0·0474	0·1290	0·1290	+·0010	+·0020	−·0010	+·0010	+·0020	1/2	1/8	1
0·0935	0·0618	0·1603	0·1603	+·0010	+·0020	−·0010	+·0010	+·0020	5/8	1/8	1 1/4
0·0935	0·0618	0·1915	0·1603	+·0010	+·0020	−·0010	+·0010	+·0020	3/4	1/4	1 1/2
0·1130	0·0725	0·2540	0·1915	+·0010	+·0020	−·0010	+·0010	+·0020	1	1/4	2
0·1325	0·0843	0·3165	0·2228	+·0010	+·0020	−·0010	+·0010	+·0020	1 1/4	1/4	2 1/2
0·1521	0·0959	0·3790	0·2540	+·0010	+·0020	−·0010	+·0010	+·0020	1 1/2	1/4	3
0·1721	0·1082	0·4425	0·2863	+·0015	+·0020	−·0015	+·0010	+·0020	1 3/4	1/4	3 1/2
0·2073	0·1355	0·5050	0·3488	+·0015	+·0040	−·0015	+·0010	+·0020	2	1/2	4
0·2269	0·1471	0·5675	0·3800	+·0015	+·0040	−·0015	+·0010	+·0020	2 1/4	1/2	4 1/2
0·2465	0·1588	0·6300	0·4113	+·0015	+·0040	−·0015	+·0010	+·0020	2 1/2	1/2	5
0 2822	0·1866	0·6945	0·4758	+·0020	+·0040	−·0020	+·0015	+·0030	3	1/2	5 1/2
0·3018	0·1982	0·7570	0·5070	+·0020	+·0040	−·0020	+·0015	+·0030	3	1/2	6
0·3746	0·2504	0·8820	0·6320	+·0020	+·0040	−·0020	+·0015	+·0030	3 1/2	1/2	7
0·4137	0·2738	1·0070	0·6945	+·0020	+·0040	−·0020	+·0015	+·0030	4	1	8
0·4528	0·2962	1·1320	0·7570	+·0020	+·0040	−·0020	+·0015	+·0030	5	1	9
0·4920	0·3195	1·2570	0·8195	+·0020	+·0040	−·0020	+·0015	+·0030	5	1	10
0·5629	0·3746	1·3830	0·9455	+·0025	+·0050	−·0025	+·0015	+·0040	6	1	11
0·6021	0·3979	1·5080	1·0080	+·0025	+·0050	−·0025	+·0015	+·0040	6	1	12
0·6413	0·4212	1·6330	1·0705	+·0025	+·0050	−·0025	+·0015	+·0040	7	1	13
0·7117	0·4758	1·7580	1·1955	+·0025	+·0050	−·0025	+·0015	+·0040	7	1	14
0·7513	0·4997	1·8850	1·2600	+·0030	+·0050	−·0030	+·0020	+·0040	8	1	15
0·8217	0·5543	2·0100	1·3850	+·0030	+·0050	−·0030	+·0020	+·0040	8	2	16
0·9046	0·5964	2·2600	1·5100	+·0030	+·0050	−·0030	+·0020	+·0040	10	2	18
0·9829	0·6431	2·5100	1·6350	+·0030	+·0050	−·0030	+·0020	+·0040	10	2	20
1·1248	0·7532	2·7620	1·8870	+·0040	+·0050	−·0040	+·0020	+·0050	12	2	22
1·2031	0·7999	3·0120	2·0120	+·0040	+·0050	−·0040	+·0020	+·0050	12	2	24

desired, they can be obtained to the nominal width and thickness of the keys with the plus specified.

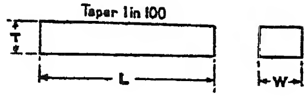
Square Taper Keys of the corresponding sizes (Table 4).

TABLE 4

BRITISH STANDARD PLAIN SQUARE TAPER KEYS, KEYWAYS AND KEY BARS

Designation	*Shaft Diameters*		*Key*			*Keyway*		
	Over	*Up to and including*	*Nominal Size, Width and Thickness*	*Min. Width* **W**	*Min. Thickness at Large End* **T**	*Max. Width in Shaft and Hub*	*Minimum Depth on Centre Line* — *In Shaft*	*Minimum Depth on Centre Line* — *In Hub at Deep End*
B.S.K. 3/32 P.S.T.	3/16	1/4	3/32 (*0·09375*)	0·0938	0·097	0·0584	0·0585	0·0354
B.S.K. 1/8 P.S.T.	1/4	3/8	1/8 (*0·125*)	0·1250	0·129	0·1250	0·0766	0·0474
B.S.K. 5/32 P.S.T.	3/8	1/2	5/32 (*0·15625*)	0·1563	0·160	0·1563	0·0935	0·0618
B.S.K. 3/16 P.S.T.	1/2	3/4	3/16 (*0·1875*)	0·1875	0·191	0·1875	0·1091	0·0774
B.S.K. 1/4 P.S.T.	3/4	1	1/4 (*0·25*)	0·2500	0·254	0·2500	0·1443	0·1037
B.S.K. 5/16 P.S.T.	1	1 1/4	5/16 (*0·3125*)	0·3125	0·316	0·3125	0·1794	0·1311
B.S.K. 3/8 P.S.T.	1 1/4	1 1/2	3/8 (*0·375*)	0·3750	0·379	0·3750	0·2146	0·1584
B.S.K. 7/16 P.S.T.	1 1/2	1 3/4	7/16 (*0·4375*)	0·4375	0·442	0·4375	0·2502	0·1863
B.S.K. 1/2 P.S.T.	1 3/4	2	1/2 (*0·5*)	0·5000	0·505	0·5000	0·2853	0·2137
B.S.K. 9/16 P.S.T.	2	2 1/4	9/16 (*0·5625*)	0·5625	0·567	0·5625	0·3207	0·2408
B.S.K. 5/8 P.S.T.	2 1/4	2 1/2	5/8 (*0·625*)	0·6250	0·630	0·6250	0·3559	0·2681
B.S.K. 11/16 P.S.T.	2 1/2	2 3/4	11/16 (*0·6875*)	0·6875	0·694	0·6875	0·3916	0·2959
B.S.K. 3/4 P.S.T.	2 3/4	3	3/4 (*0·75*)	0·7500	0·757	0·7500	0·4268	0·3232
B.S.K. 7/8 P.S.T.	3	3 1/2	7/8 (*0·375*)	0·8750	0·882	0·8750	0·4996	0·3754
B.S.K. 1 P.S.T.	3 1/2	4	1	1·0000	1·007	1·0000	0·5700	0·4300
B.S.K. 1 1/8 P.S.T.	4	4 1/2	1 1/8 (*1·125*)	1·1250	1·132	1·1250	0·6403	0·4837
B.S.K. 1 1/4 P.S.T.	4 1/2	5	1 1/4 (*1·25*)	1·2500	1·257	1·2500	0·7108	0·5382
B.S.K. 1 3/8 P.S.T.	5	5 1/2	1 3/8 (*1·375*)	1·3750	1·383	1·3750	0·7817	0·5933
B.S.K. 1 1/2 P.S.T.	5 1/2	6	1 1/2 (*1·5*)	1·5000	1·508	1·5000	0·8521	0·6479
B.S.K. 1 5/8 P.S.T.	6	6 1/2	1 5/8 (*1·625*)	1·6250	1·633	1·6250	0·9226	0·7024
B.S.K. 1 3/4 P.S.T.	6 1/2	7	1 3/4 (*1·75*)	1·7500	1·758	1·7500	0·9930	0·7570
B.S.K. 1 7/8 P.S.T.	7	7 1/2	1 7/8 (*1·875*)	1·8750	1·885	1·8750	1·0638	0·8122
B.S.K. 2 P.S.T.	7 1/2	8	2	2·0000	2·010	2·0000	1·1342	0·8668
B.S.K. 2 1/4 P.S.T.	8	9	2 1/4 (*2·25*)	2·2500	2·260	2·2500	1·2796	0·9714
B.S.K. 2 1/2 P.S.T.	9	10	2 1/2 (*2·5*)	2·5000	2·510	2·5000	1·4204	1·0806
B.S.K. 2 3/4 P.S.T.	10	11	2 3/4 (*2·75*)	2·7500	2·762	2·7500	1·5623	1·1907
B.S.K. 3 P.S.T.	11	12	3	3 0000	3·012	3·0000	1·7031	1·2999

* Where Key Bars are required to produce keys for which a fitting allowance is not desired, tolerances



(All Dimensions are in Inches)

Finished Key Bar* (see footnote)	Tolerances					Standard Lengths L		
Minimum Width and Thickness	On Key		On Keyway		On Key Bar	Minimum	Increasing by	Maximum
	Width −·0000	Thickness −·0000	Width +·0000	Depth −·0000	Width and Thickness −·0000			
0·0978	+·0010	+·0020	−·0010	+·0010	+·0020	3/8	1/8	3/4
0·1290	+·0010	+·0020	−·0010	+·0010	+·0020	1/2	1/8	1
0·1603	+·0010	+·0020	−·0010	+·0010	+·0020	5/8	1/8	1¼
0·1915	+·0010	+·0020	−·0010	+·0010	+·0020	3/4	1/4	1½
0·2540	+·0010	+·0020	−·0010	+·0010	+·0020	1	1/4	2
0·3165	+·0010	+·0020	−·0010	+·0010	+·0020	1¼	1/4	2½
0·3790	+·0010	+·0020	−·0010	+·0010	+·0020	1½	1/4	3
0·4425	+·0015	+·0020	−·0015	+·0010	+·0020	1¾	1/4	3½
0·5050	+·0015	+·0040	−·0015	+·0010	+·0020	2	1/2	4
0·5675	+·0015	+·0040	−·0015	+·0010	+·0020	2½	1/2	4½
0·6300	+·0015	+·0040	−·0015	+·0010	+·0020	2½	1/2	5
0·6945	+·0020	+·0040	−·0020	+·0015	+·0030	3	1/2	5½
0·7570	+·0020	+·0040	−·0020	+·0015	+·0030	3	1/2	6
0·8820	+·0020	+·0040	−·0020	+·0015	+·0030	3½	1/2	7
1·0070	+·0020	+·0040	−·0020	+·0015	+·0030	4	1	8
1·1320	+·0020	+·0040	−·0020	+·0015	+·0030	5	1	9
1·2570	+·0020	+·0040	−·0020	+·0015	+·0030	5	1	10
1·3830	+·0025	+·0050	−·0025	+·0015	+·0040	6	1	11
1·5080	+·0025	+·0050	−·0025	+·0015	+·0040	6	1	12
1·6330	+·0025	+·0050	−·0025	+·0015	+·0040	7	1	13
1·7580	+·0025	+·0050	−·0025	+·0015	+·0040	7	1	14
1·8850	+·0030	+·0050	−·0030	+·0020	+·0040	8	1	15
2·0100	+·0030	+·0050	−·0030	+·0020	+·0040	8	2	16
2·2600	+·0030	+·0050	−·0030	+·0020	+·0040	10	2	18
2·5100	+·0030	+·0050	−·0030	+·0020	+·0040	10	2	20
2·7620	+·0040	+·0050	−·0040	+·0020	+·0040	12	2	22
3·0120	+·0040	+·0050	−·0040	+·0020	+·0050	12	2	24

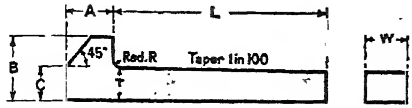
they can be obtained to the nominal width and thickness of the keys with the plus specified.

TABLE 5

BRITISH STANDARD GIB-HEAD RECTANGULAR TAPER KEYS AND KEYWAYS

Designation	*Shaft Diameters*		*Key*				*Gib-*	
	Over	*Up to and including*	*Nominal Size* — *Width*	*Nominal Size* — *Thickness*	*Min. Width* **W**	*Min. Thickness at Large End* **T**	**A**	**B**
B.S.K. 3/32 G.R.T.†	3/16	1/4	3/32 *(0·09375)*	3/32 *(0·09375)*	0·0938	0·099	5/32	7/32
B.S.K. 1/8 G.R.T.†	1/4	3/8	1/8 *(0·125)*	1/8 *(0·125)*	0·1250	0·130	3/16	9/32
B.S.K. 5/32 G.R.T.†	3/8	1/2	5/32 *(0·15625)*	5/32 *(0·15625)*	0·1563	0·162	7/32	5/16
B.S.K. 3/16 G.R.T.	1/2	3/4	3/16 *(0·1875)*	5/32 *(0·15625)*	0·1875	0·162	1/4	11/32
B.S.K. 1/4 G.R.T.	3/4	1	1/4 *(0·25)*	3/16 *(0·1875)*	0·2500	0·194	5/16	13/32
B.S.K. 5/16 G.R.T.	1	1 1/4	5/16 *(0·3125)*	7/32 *(0·21875)*	0·3125	0·226	3/8	15/32
B.S K. 3/8 G.R.T.	1 1/4	1 1/2	3/8 *(0·375)*	1/4 *(0·25)*	0·3750	0·258	7/16	17/32
B.S.K. 7/16 G.R.T.	1 1/2	1 3/4	7/16 *(0·4375)*	9/32 *(0·28125)*	0·4375	0·291	1/2	19/32
B.S.K. 1/2 G.R.T.	1 3/4	2	1/2 *(0·5)*	11/32 *(0·34375)*	0·5000	0·354	9/16	11/16
B.S.K. 9/16 G.R.T.	2	2 1/4	9/16 *(0·5625)*	3/8 *(0·375)*	0·5625	0·386	5/8	3/4
B.S.K. 5/8 G.R.T.	2 1/4	2 1/2	5/8 *(0·625)*	13/32 *(0·40625)*	0·6250	0·418	11/16	13/16
B.S.K. 11/16 G.R.T.	2 1/2	2 3/4	11/16 *(0·6875)*	15/32 *(0·46875)*	0·6875	0·483	3/4	29/32
B.S.K. 3/4 G.R.T.	2 3/4	3	3/4 *(0·75)*	1/2 *(0·5)*	0·7500	0·515	13/16	31/32
B.S.K. 7/8 G.R.T.	3	3 1/2	7/8 *(0·875)*	5/8 *(0·625)*	0·8750	0·641	15/16	1 5/32
B.S.K. 1 G.R.T.	3 1/2	4	1	11/16 *(0·6875)*	1·0000	0·705	1 1/16	1 9/32
B.S.K. 1 1/8 G.R.T.	4	4 1/2	1 1/8 *(1·125)*	3/4 *(0·75)*	1·1250	0·768	1 3/16	1 13/32
B.S.K. 1 1/4 G.R.T.	4 1/2	5	1 1/4 *(1·25)*	13/16 *(0·8125)*	1·2500	0·832	1 5/16	1 17/32
B.S.K. 1 3/8 G.R.T.	5	5 1/2	1 3/8 *(1·375)*	15/16 *(0·9375)*	1·3750	0·959	1 7/16	1 23/32
B.S.K. 1 1/2 G.R.T.	5 1/2	6	1 1/2 *(1·5)*	1	1·5000	1·023	1 9/16	1 27/32
B.S.K. 1 5/8 G.R.T.	6	6 1/2	1 5/8 *(1·625)*	1 1/16 *(1·0625)*	1·6250	1·087	1 11/16	1 31/32
B.S.K. 1 3/4 G.R.T.	6 1/2	7	1 3/4 *(1·75)*	1 3/16 *(1·1875)*	1·7500	1·213	1 13/16	2 5/32
B.S.K. 1 7/8 G.R.T.	7	7 1/2	1 7/8 *(1·875)*	1 1/4 *(1·25)*	1·8750	1·279	1 15/16	2 9/32
B.S.K. 2 G.R.T.	7 1/2	8	2	1 3/8 *(1·375)*	2·0000	1·405	2 1/16	2 15/32
B.S.K. 2 1/4 G.R.T.	8	9	2 1/4 *(2·25)*	1 1/2 *(1·5)*	2·2500	1·533	2 5/16	2 3/4
B.S.K. 2 1/2 G.R.T.	9	10	2 1/2 *(2·5)*	1 5/8 *(1·625)*	2·5000	1·660	2 9/16	3
B.S.K. 2 3/4 G.R.T.	10	11	2 3/4 *(2.75)*	1 7/8 *(1·875)*	2·7500	1·915	2 13/16	3 3/8
B.S.K. 3 G.R.T.	11	12	3	2	3·0000	2·042	3 1/16	3 5/8

† These keys are identical with the B.S. Gib-head



(All Dimensions are in Inches)

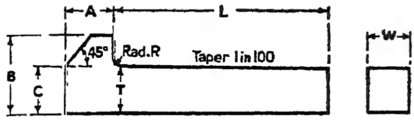
head		Keyway			Tolerances				Standard Lengths L		
			Min. Depth on Centre Line		On Key		On Keyway				
C	Radius at Junction of Head	Max. Width in Shaft and Hub	In Shaft	In Hub at Deep End	Width −·0000	Thickness −·0000	Width +·0000	Depth −·0000	Min.	Increasing by	Max.
1/8	1/32	0·0938	0·0584	0·0354	+·0010	+·0020	−·0010	+·0010	1/2	1/8	7/8
5/32	1/32	0·1250	0·0766	0·0474	+·0010	+·0020	−·0010	+·0010	5/8	1/8	1 1/8
3/16	1/32	0·1563	0·0935	0·0618	+·0010	+·0020	−·0010	+·0010	3/4	1/8	1 1/4
3/16	1/32	0·1875	0·0935	0·0618	+·0010	+·0020	−·0010	+·0010	1	1/4	1 3/4
7/32	1/16	0·2500	0·1130	0·0725	+·0010	+·0020	−·0010	+·0010	1 1/4	1/4	2 1/4
1/4	1/16	0·3125	0·1325	0·0843	+·0010	+·0020	−·0010	+·0010	1 1/2	1/4	2 3/4
9/32	1/16	0·3750	0·1521	0·0959	+·0010	+·0020	−·0010	+·0010	2	1/4	3 1/2
5/16	1/16	0·4375	0·1721	0·1082	+·0015	+·0020	−·0015	+·0010	2 1/4	1/4	4
3/8	1/16	0·5000	0·2073	0·1355	+·0015	+·0040	−·0015	+·0010	2 1/2	1/2	4 1/2
11/32	1/8	0·5625	0·2269	0·1471	+·0015	+·0040	−·0015	+·0010	3	1/2	5
7/16	1/8	0·6250	0·2465	0·1588	+·0015	+·0040	−·0015	+·0010	3	1/2	5 1/2
1/2	1/8	0·6875	0·2822	0·1866	+·0020	+·0040	−·0020	+·0015	3 1/2	1/2	6
17/32	1/8	0·7500	0·3018	0·1982	+·0020	+·0040	−·0020	+·0015	4	1/2	7
21/32	1/8	0·8750	0·3746	0·2504	+·0020	+·0040	−·0020	+·0015	4 1/2	1/2	8
23/32	1/8	1·0000	0·4137	0·2738	+·0020	+·0040	−·0020	+·0015	5	1	9
25/32	1/4	1·1250	0·4528	0·2962	+·0020	+·0040	−·0020	+·0015	6	1	10
27/32	1/4	1·2500	0·4920	0·3195	+·0020	+·0040	−·0020	+·0015	6	1	11
31/32	1/4	1·3750	0·5629	0·3746	+·0025	+·0050	−·0025	+·0015	7	1	12
1 1/32	1/4	1·5000	0·6021	0·3979	+·0025	+·0050	−·0025	+·0015	8	1	14
1 3/32	1/4	1·6250	0·6413	0·4212	+·0025	+·0050	−·0025	+·0015	8	1	15
1 7/32	1/4	1·7500	0·7117	0·4758	+·0025	+·0050	−·0025	+·0015	9	1	16
1 9/32	1/4	1·8750	0·7513	0·4997	+·0030	+·0050	−·0030	+·0020	9	1	17
1 11/32	1/4	2·0000	0·8217	0·5543	+·0030	+·0050	−·0030	+·0020	10	2	18
1 9/16	3/8	2·2500	0·9046	0·5964	+·0030	+·0050	−·0030	+·0020	11	2	21
1 11/16	3/8	2·5000	0·9829	0·6431	+·0030	+·0050	−·0030	+·0020	12	2	22
1 15/16	3/8	2·7500	1·1248	0·7532	+·0040	+·0050	−·0040	+·0020	14	2	24
2 1/16	3/8	3·0000	1·2031	0·7999	+·0040	+·0050	−·0040	+·0020	15	2	27

Square Taper Keys of the corresponding sizes (Table 6).

TABLE 6

BRITISH STANDARD GIB-HEAD SQUARE TAPER KEYS AND KEYWAYS

Designation	*Shaft Diameters*		*Key*			*Gib-head*		
	Over	*Up to and including*	*Nominal Size, Width and Thickness*	*Minimum Width* **W**	*Minimum Thickness at Large End* **T**	**A**	**B**	**C**
B.S.K. $\frac{3}{32}$ G.S.T.	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{32}$ (0·09375)	0·0938	0·099	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{1}{8}$
B.S.K. $\frac{1}{8}$ G.S.T	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{8}$ (0·125)	0·1250	0·130	$\frac{3}{16}$	$\frac{9}{32}$	$\frac{5}{32}$
B.S.K. $\frac{5}{32}$ G.S.T.	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{32}$ (0·15625)	0·1563	0·162	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{3}{16}$
B.S.K. $\frac{3}{16}$ G.S.T.	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{16}$ (0·1875)	0·1875	0·193	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{7}{32}$
B.S.K. $\frac{1}{4}$ G.S.T.	$\frac{3}{4}$	1	$\frac{1}{4}$ (0·25)	0·2500	0·257	$\frac{5}{16}$	$\frac{15}{32}$	$\frac{9}{32}$
B.S.K. $\frac{5}{16}$ G.S.T.	1	$1\frac{1}{4}$	$\frac{5}{16}$ (0·3125)	0·3125	0·320	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{11}{32}$
B.S.K. $\frac{3}{8}$ G.S.T.	$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{3}{8}$ (0·375)	0·3750	0·383	$\frac{7}{16}$	$\frac{21}{32}$	$\frac{13}{32}$
B.S.K. $\frac{7}{16}$ G.S.T.	$1\frac{1}{2}$	$1\frac{3}{4}$	$\frac{7}{16}$ (0·4375)	0·4375	0·447	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{15}{32}$
B.S.K. $\frac{1}{2}$ G.S.T.	$1\frac{3}{4}$	2	$\frac{1}{2}$ (0·5)	0·5000	0·510	$\frac{9}{16}$	$\frac{27}{32}$	$\frac{17}{32}$
B.S.K. $\frac{9}{16}$ G.S.T.	2	$2\frac{1}{4}$	$\frac{9}{16}$ (0·5625)	0·5625	0·573	$\frac{5}{8}$	$\frac{15}{16}$	$\frac{19}{32}$
B.S.K. $\frac{5}{8}$ G.S.T.	$2\frac{1}{4}$	$2\frac{1}{2}$	$\frac{5}{8}$ (0·625)	0·6250	0·636	$\frac{11}{16}$	$1\frac{1}{32}$	$\frac{21}{32}$
B.S.K. $\frac{11}{16}$ G.S.T.	$2\frac{1}{2}$	$2\frac{3}{4}$	$\frac{11}{16}$ (0·6375)	0·6875	0·701	$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{23}{32}$
B.S.K. $\frac{3}{4}$ G.S.T.	$2\frac{3}{4}$	3	$\frac{3}{4}$ (0·75)	0·7500	0·765	$\frac{13}{16}$	$1\frac{7}{32}$	$\frac{25}{32}$
B.S.K. $\frac{7}{8}$ G.S.T.	3	$3\frac{1}{2}$	$\frac{7}{8}$ (0·875)	0·8750	0·891	$\frac{15}{16}$	$1\frac{13}{32}$	$\frac{29}{32}$
B.S.K. 1 G.S.T.	$3\frac{1}{2}$	4	1	1·0000	1·017	$1\frac{1}{16}$	$1\frac{19}{32}$	$1\frac{1}{32}$
B.S.K. $1\frac{1}{8}$ G.S.T.	4	$4\frac{1}{2}$	$1\frac{1}{8}$ (1·125)	1·1250	1·143	$1\frac{3}{16}$	$1\frac{25}{32}$	$1\frac{5}{32}$
B.S.K. $1\frac{1}{4}$ G.S.T.	$4\frac{1}{2}$	5	$1\frac{1}{4}$ (1·25)	1·2500	1·270	$1\frac{5}{16}$	$1\frac{31}{32}$	$1\frac{9}{32}$
B.S.K. $1\frac{3}{8}$ G.S.T.	5	$5\frac{1}{2}$	$1\frac{3}{8}$ (1·375)	1·3750	1·397	$1\frac{7}{16}$	$2\frac{5}{32}$	$1\frac{13}{32}$
B.S.K. $1\frac{1}{2}$ G.S.T.	$5\frac{1}{2}$	6	$1\frac{1}{2}$ (1·5)	1·5000	1·523	$1\frac{9}{16}$	$2\frac{11}{32}$	$1\frac{17}{32}$
B.S.K. $1\frac{5}{8}$ G.S.T.	6	$6\frac{1}{2}$	$1\frac{5}{8}$ (1·625)	1·6250	1·649	$1\frac{11}{16}$	$2\frac{17}{32}$	$1\frac{21}{32}$
B.S.K. $1\frac{3}{4}$ G.S.T.	$6\frac{1}{2}$	7	$1\frac{3}{4}$ (1·75)	1·7500	1·776	$1\frac{13}{16}$	$2\frac{23}{32}$	$1\frac{25}{32}$
B.S.K. $1\frac{7}{8}$ G.S.T.	7	$7\frac{1}{2}$	$1\frac{7}{8}$ (1·875)	1·8750	1·904	$1\frac{15}{16}$	$2\frac{29}{32}$	$1\frac{29}{32}$
B.S.K. 2 G.S.T.	$7\frac{1}{2}$	8	2	2·0000	2·030	$2\frac{1}{16}$	$3\frac{3}{32}$	$2\frac{1}{32}$
B.S.K. $2\frac{1}{4}$ G.S.T.	8	9	$2\frac{1}{4}$ (2·25)	2·2500	2·283	$2\frac{5}{16}$	$3\frac{1}{2}$	$2\frac{5}{16}$
B.S.K. $2\frac{1}{2}$ G.S.T.	9	10	$2\frac{1}{2}$ (2·5)	2·5000	2·535	$2\frac{9}{16}$	$3\frac{7}{8}$	$2\frac{9}{16}$
B.S.K. $2\frac{3}{4}$ G.S.T.	10	11	$2\frac{3}{4}$ (2·75)	2·7500	2·790	$2\frac{13}{16}$	$4\frac{1}{4}$	$2\frac{13}{16}$
B.S.K. 3 G.S.T.	11	12	3	3·0000	3·042	$3\frac{1}{16}$	$4\frac{5}{8}$	$3\frac{1}{16}$



(All Dimensions are in Inches)

Radius at Junction of Head in R	Keyway: Maximum Width Shaft and Hub	Keyway: Minimum Depth on Centre Line: In Shaft	Keyway: Minimum Depth on Centre Line: In Hub at Deep End	Tolerances: On Key: Width −·0000	Tolerances: On Key: Thickness −·0000	Tolerances: On Keyway: Width +·0000	Tolerances: On Keyway: Depth −·0000	Standard Lengths L: Minimum	Standard Lengths L: Increasing by	Standard Lengths L: Maximum
1/32	0·0938	0·0584	0·0354	+·0010	+·0020	−·0010	+·0010	1/2	1/8	7/8
1/32	0·1250	0·0766	0·0474	+·0010	+·0020	−·0010	+·0010	5/8	1/8	1 1/8
1/32	0·1563	0·0935	0·0618	+·0010	+·0020	−·0010	+·0010	3/4	1/8	1 1/2
1/16	0·1875	0·1091	0·0774	+·0010	+·0020	−·0010	+·0010	1	1/4	1 3/4
1/16	0·2500	0·1443	0·1037	+·0010	+·0020	−·0010	+·0010	1 1/4	1/4	2 1/4
1/16	0·3125	0·1794	0·1311	+·0010	+·0020	−·0010	+·0010	1 1/2	1/4	2 3/4
1/16	0·3750	0·2146	0·1584	+·0010	+·0020	−·0010	+·0010	2	1/4	3 1/2
1/16	0·4375	0·2502	0·1863	+·0015	+·0020	−·0015	+·0010	2 1/4	1/4	4
1/16	0·5000	0·2853	0·2137	+·0015	+·0040	−·0015	+·0010	2 1/2	1/2	4 1/2
1/8	0·5625	0·3207	0·2408	+·0015	+·0040	−·0015	+·0010	3	1/2	5
1/8	0·6250	0·3559	0·2681	+·0015	+·0040	−·0015	+·0010	3	1/2	5 1/2
1/8	0·6875	0·3916	0·2959	+·0020	+·0040	−·0020	+·0015	3 1/2	1/2	6
1/8	0·7500	0·4268	0·3232	+·0020	+·0040	−·0020	+·0015	4	1/2	7
1/8	0·8750	0·4996	0·3754	+·0020	+·0040	−·0020	+·0015	4 1/2	1/2	8
1/8	1·0000	0·5700	0·4300	+·0020	+·0040	−·0020	+·0015	5	1	9
1/4	1·1250	0·6403	0·4837	+·0020	+·0040	−·0020	+·0015	6	1	10
1/4	1·2500	0·7108	0·5382	+·0020	+·0040	−·0020	+·0015	6	1	11
1/4	1·3750	0·7817	0·5933	+·0025	+·0050	−·0025	+·0015	7	1	12
1/4	1·5000	0·8521	0·6479	+·0025	+·0050	−·0025	+·0015	8	1	14
1/4	1·6250	0·9226	0·7024	+·0025	+·0050	−·0025	+·0015	8	1	15
1/4	1·7500	0·9930	0·7570	+·0025	+·0050	−·0025	+·0015	9	1	16
1/4	1·8750	1·0638	0·8122	+·0030	+·0050	−·0030	+·0020	9	1	17
1/4	2·0000	1·1342	0·8668	+·0030	+·0050	−·0030	+·0020	10	2	18
3/8	2·2500	1·2796	0·9714	+·0030	+·0050	−·0030	+·0020	11	2	21
3/8	2·5000	1·4204	1·0806	+·0030	+·0050	−·0030	+·0020	12	2	22
3/8	2·7500	1·5623	1·1907	+·0040	+·0050	−·0040	+·0020	14	2	24
3/8	3·0000	1·7031	1·2999	+·0040	+·0050	−·0040	+·0020	15	2	27

TABLE 7

BRITISH STANDARD PEG FEATHER KEYS

(See p. 462)

(All Dimensions are in Inches)

Size of Key	W	T	L					A	B	D
3/32	3/32	3/32	3/8	15/32	9/16	21/32	3/4	3/32	3/32	3/32
1/8	1/8	1/8	1/2	5/8	3/4	7/8	1	1/8	1/8	1/8
5/32	5/32	5/32	5/8	25/32	15/16	1 3/32	1 1/4	5/32	5/32	5/32
3/16	3/16	3/16	3/4	15/16	1 1/8	1 5/16	1 1/2	3/16	3/16	3/16
1/4	1/4	1/4	1	1 1/4	1 1/2	1 3/4	2	1/4	1/4	1/4
5/16	5/16	5/16	1 1/4	1 9/16	1 7/8	2 3/16	2 1/2	5/16	5/16	5/16
3/8	3/8	3/8	1 1/2	1 7/8	2 1/4	2 5/8	3	3/8	3/8	3/8
7/16	7/16	7/16	1 3/4	2 3/16	2 5/8	3 1/16	3 1/2	7/16	7/16	7/16
1/2	1/2	1/2	2	2 1/2	3	3 1/2	4	1/2	1/2	1/2
9/16	9/16	9/16	2 1/4	2 13/16	3 3/8	3 15/16	4 1/2	9/16	9/16	9/16
5/8	5/8	5/8	2 1/2	3 1/8	3 3/4	4 3/8	5	5/8	5/8	5/8
3/4	3/4	3/4	3	3 3/4	4 1/2	5 1/4	6	3/4	3/4	3/4
7/8	7/8	7/8	3 1/2	4 3/8	5 1/4	6 1/8	7	7/8	7/8	7/8
1	1	1	4	5	6	7	8	1	1	1

KEY PROPORTIONS

It will be noted that key proportions are not decided by the torsional load, but are decided according to the diameter of shaft, and many rules have been evolved for settling the proportion of the keys on this basis. The B.S.I. standards are not always adopted, but it is suggested that in future key proportions should be settled and specified according to the tables herein given.

For the guidance of those who do not follow B.S.I. recommendations, the following formulæ for key proportions are given.

Width of key = $\frac{1}{4}$ diameter of shaft up to 4 in.
$\frac{1}{5}$ diameter of shaft, 4–8 in.
$\frac{1}{6}$ diameter of shaft, 8–12 in.
Key square at thick end, taper $\frac{1}{4}$ in. per foot.
One-third of thickness let in shaft, remainder in wheel.

Another rule:

Width of key = $\frac{1}{4}$ diameter of shaft plus $\frac{1}{8}$ in.
Middle thickness = $\frac{1}{8}$ diameter of shaft plus $\frac{1}{8}$ in. (Adams.)

Proportions of Cotters through Bars

b = Breadth of cotter. t = Thickness of cotter. d = Diameter of bar.

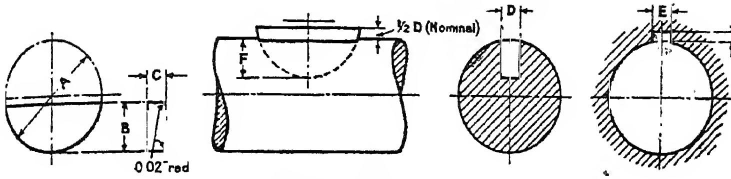
Through round bars : $b = 1{\cdot}4635d$. $t = \frac{d}{5}$.

Through square bars : $b = 1{\cdot}5$ side of bar. $t = \frac{\text{side of bar}}{4}$.

Taper of cotters = 1 in 32.

TABLE 8

BRITISH STANDARD WOODRUFF KEYS AND KEYWAYS



(All Dimensions are in Inches)

B.S. Key Number	Diameter of Key A	Depth of Key B	Thickness of Key C	Width of Keyway in Shaft D	Width of Keyway in Hub or Boss E	Depth of Keyway in Shaft F	Depth of Keyway in Hub at Centre Line G	Corresponding B.S. Woodruff Cutter Numbers
	+ 0 − 0·005	+ 0 − 0 005	+ 0 − 0·001	− 0 + 0·001	− 0 + 0·001	− 0 + 0 005	− 0 + 0·005	
10	0·500	0 203	0·0635	0·0615	0·0635	0·1668	0·042	1
20	0·500	0·203	0·0948	0·0928	0·0948	0·1511	0·057	2
30	0·500	0·203	0·1260	0·1240	0·1260	0·1355	0·073	3
40	0·625	0·250	0·0948	0·0928	0·0948	0·1981	0·057	4
50	0·625	0·250	0·1260	0·1240	0·1260	0·1825	0·073	5
60	0·625	0·250	0·1573	0·1553	0·1573	0·1669	0·089	6
70	0·750	0·313	0·1260	0·1240	0·1260	0·2455	0·073	7
80	0·750	0·313	0·1573	0·1553	0·1573	0·2299	0·089	8
90	0·750	0·313	0·1885	0·1865	0·1885	0·2143	0·104	9
100	0·875	0·375	0·1573	0·1553	0·1573	0·2919	0·089	10
110	0·875	0·375	0·1885	0·1865	0·1885	0·2763	0·104	11
115	0·875	0·375	0·2510	0·2490	0·2510	0·2450	0·136	A
130	1·000	0·438	0·1885	0·1865	0·1885	0·3393	0·104	13
150	1·000	0·438	0·2510	0·2490	0·2510	0·3080	0·136	15
155	1·000	0·438	0·3135	0·3115	0·3135	0·2768	0·167	B
160	1·125	0·484	0·1885	0·1865	0·1885	0·3853	0·104	16
180	1·125	0·484	0·2510	0·2490	0·2510	0·3540	0·136	18
185	1·125	0·484	0·3135	0·3115	0·3135	0·3228	0·167	C
210	1·250	0·547	0·2510	0·2490	0·2510	0·4170	0·136	21
215	1·250	0·547	0·3135	0·3115	0·3135	0·3858	0·167	D
225	1·250	0·547	0·3760	0·3740	0·3760	0·3545	0·198	E
230	1·375	0·594	0·3135	0·3115	0·3135	0·4328	0·167	23
235	1·375	0·594	0·3760	0·3740	0·3760	0·4015	0·198	F
240	1·500	0·641	0·2510	0·2490	0·2510	0·5110	0·136	24
250	1·500	0·641	0·3135	0·3115	0·3135	0·4798	0·167	25
255	1·500	0·641	0·3760	0·3740	0·3760	0·4485	0·198	G

For particulars of the British Standard Cutters for producing the Woodruff Keyways see Table XXXI of B.S. Specification No. 122 for Milling Cutters and Reamers.

TABLE 10

TYPE B. TANGENTIAL KEYS

Key Range		*Standard Diameter of Shaft*	*Shaft*		*Hub*	
Diameter of Shaft	*Assembled Keys* **W × T**	**D**	**A**	**B**	**C**	**E**
4 and under 5	7/8 × 1/2	4 4¼ 4½ 4¾	1·500 1·500 1·625 1·625	2·875 3·000 3·250 3·500	3·875 4·000 4·250 4·500	0·625 0·625 0·750 0·750
5 and under 6	1 × 1/2	5 5¼ 5½ 5¾	1·875 2·000 2·000 2·125	3·750 4·000 4·250 4·500	4·750 5·000 5·250 5·500	0·875 1·000 1·000 1·125
6 and under 7	1⅛ × 5/8	6 6¼ 6½ 6¾	2·125 2·250 2·250 2·375	4·500 4·750 4·875 5·125	5·750 6·000 6·125 6·375	1·000 1·125 1·125 1·250
7 and under 8	1¼ × 3/4	7 7½	2·375 2·500	5·125 5·500	6·625 7·000	1·125 1·250
8 and under 10	1⅜ × 7/8	8 8½ 9 9½	2·750 2·875 3·000 3·125	5·875 6·250 6·750 7·125	7·625 8·000 8·500 8·875	1·250 1·375 1·500 1·625
10 and under 12	1⅝ × 1	10 10½ 11 11½	3·375 3·625 3·750 3·875	7·375 8·000 8·375 8·875	9·375 10·000 10·375 10·875	1·625 1·875 2·000 2·125
12 and under 14	2⅛ × 1¼	12 12½ 13 13½	4·125 4·250 4·375 4·500	8·875 9·375 9·750 10·250	11·375 11·875 12·250 12·750	2·000 2·125 2·250 2·375

To locate keyways for intermediate diameters of

$$B = W\sqrt{\frac{D^2 - W^2 - T^2}{W + T}} - T$$

(See Fig 27.)

(All Dimensions are in Inches)

Key Range		*Standard Diameter of Shaft*	*Shaft*		*Hub*	
Diameter of Shaft	*Assembled Keys* W × T	D	A	B	C	E
14 and under 16	2½ × 1½	14 14½ 15	4·750 4·875 5·125	10·250 10·625 11·250	13·250 13·625 14·250	2·250 2·375 2·625
16 and under 18	3 × 1⅝	16 17	5·625 5·875	11·750 12·625	15·250 16·125	2·625 2·875
18 and under 21	3½ × 2	18 19 20	6·375 6·625 6·875	13·250 14·125 15·000	17·250 18·125 19·000	2·875 3·125 3·375
21 and under 24	3⅞ × 2¼	21 22 23	7·375 7·625 7·750	15·625 16·500 17·250	20·125 21·000 21·750	3·500 3·750 3·875
24 and under 27	4⅜ × 2½	24 25 26	8·250 8·625 8·875	17·750 18·750 19·625	22·750 23·750 24·625	3·875 4·250 4·500
27 and under 30	4⅞ × 2¾	27 28 29	9·375 9·625 9·875	20·125 21·000 21·875	25·625 26·500 27·375	4·500 4·750 5·000
30 and under 33	5½ 3	30 31 32	10·375 10·500 10·750	22·500 23·250 24·125	28·500 29·250 30·125	5·125 5·250 5·500
33 to 36 inclusive	5⅝ × 3¼	33 34 35 36	11·125 11·500 11·875 12·375	24·625 25·750 26·625 27·750	31·125 32·250 33·125 34·250	5·500 5·875 6·250 6·750

shafts the following formulæ should be used :—

$$E = \frac{D - \sqrt{D^2 - B^2}}{12}$$

TABLE 9

The following Table gives the sizes of keys based on the proportions given on pp. 478 and 479 for shafts of 4 to 36 in. diameter. (See Figs. 26 and 27.)

(All Dimensions are in Inches)

Diameter of Shaft D	*Width of Keys* W	*Thickness of Keys* T	*Diameter of Shaft* D	*Width of Keys* W	*Thickness of Keys* T	*Diameter of Shaft* D	*Width of Keys* W	*Thickness of Keys* T
4	1·200	0·400	9½	2·850	0·950	21	6·300	2·100
4¼	1·275	0·425	10	3·000	1·000	22	6·600	2·200
4½	1·350	0·450	10½	3·150	1·050	23	6·900	2·300
4¾	1·425	0·475	11	3·300	1·100	24	7·200	2·400
5	1·500	0·500	11½	3·450	1·150	25	7·500	2·500
5¼	1·575	0·525	12	3·600	1·200	26	7·800	2·600
5½	1·650	0·550	12½	3·750	1·250	27	8·100	2·700
5¾	1·725	0·575	13	3·900	1·300	28	8·400	2·800
6	1·800	0·600	13½	4·050	1·350	29	8·700	2·900
6¼	1·875	0·625	14	4·200	1·400	30	9·000	3·000
6½	1·950	0·650	14½	4·350	1·450	31	9·300	3·100
6¾	2·025	0·675	15	4·500	1·500	32	9·600	3·200
7	2·100	0·700	16	4·800	1·600	33	9·900	3·300
7½	2·250	0·750	17	5·100	1·700	34	10·200	3·400
8	2·400	0·800	18	5·400	1·800	35	10·500	3·500
8½	2·550	0·850	19	5·700	1·900	36	10·800	3·600
9	2·700	0·900	20	6·000	2·000			

The above dimensions are based on the formulæ W=0·3 D and T=0·1 D, but for an intermediate diameter of shaft the key section shall be the same as that for the next size larger shaft in the above list.

SPLINE HOBS

In the design of a spline hob, the first consideration is the location of the pitch-line diameter of generation on the spline shaft. If this is made too large the resultant fillet in the roots of the splines becomes excessive, whilst if it is taken too near the root diameter of the splines the hob profile becomes too upright near its base. This causes the hob to have a poor cutting action, as rubbing takes place at the points where the inclination is low, the cutting clearance being small, no matter how large a cam is used in the relieving operation.

The best compromise is usually to fix the pitch-line diameter of generation at the outside diameter of the spline shaft, or at a diameter of about 0·03 in. less than this.

Let pitch-line diameter of generation = P.L.G.

Then normal pitch $= \dfrac{\text{P.L.G.} \times \pi}{\text{Number of splines}}$.

Addendum of hob = ½(P.L.G. − root diameter of spline).

The outside diameter of the hob should be as large as practicable, having regard to clearances on the hobbing machine and on the spline shaft itself.

Pitch-line diameter of hob = out. dia. of Hob − 2 × add. of hob.

Find worm angle of hob from:

$$\text{sin worm angle} = \frac{\text{Normal pitch} \times \text{No. of starts}}{\text{P.L.D. of hob} \times \pi}.$$

(The number of starts is usually ONE for a finishing hob.)

$$\text{Lead of hob} = \frac{\text{Normal pitch} \times \text{No. of starts}}{\text{cos worm angle}}.$$

The thickness of the hob tooth at the pitch line is equal to the normal pitch-arc thickness of spline, i.e.:

Thickness normal pitch = P.L.G. × (Angle of generation in radians),

the angle of generation being obtained from:

$$\text{sin angle of generation} = \frac{\text{Width of spline}}{\text{P.L.G.}},$$

Capstan Lathe.—A lathe possessing the unique feature of a rotating tool head or turret mounted upon a ram in place of the tailstock (hence American definition, Ram-type Turret Lathe).

Other features include adjustable stops to all slides, rugged construction, and simplicity of operation (see Fig. 1).

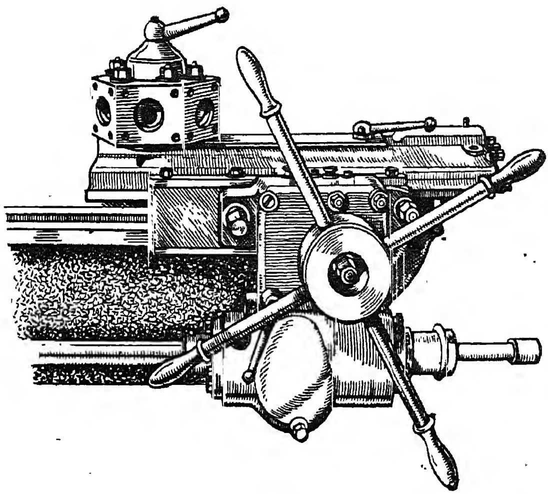


Fig. 1.—The turret head of a capstan lathe is carried on a separate slide.

Turret Lathe.—A similar machine to the capstan lathe. The main difference lies in the fact that the turret head is mounted directly upon the bed of the machine. This results in a steadier machine, which is slightly slower in operation but more eminently suitable for heavy work (see Fig. 2).

Choosing a Capstan.—Main points to note.

Capacity.—Check : (*a*) Mandrel bore against rod size for bar work.

(*b*) Clearance over ways and saddle in conjunction with chuck size and capacity for castings, etc.

(*c*) Stroke of capstan head against turned length of component.

Questions : (*a*) Are spindle speeds of right order to suit diameter and material of work-piece ?

(*b*) Do feeds correspond with finishes required ?

Design.—(*a*) Is turret robust enough for job in mind ?

(*b*) Is saddle of good length and of ample bearing surface ?

(*c*) Does turret index definitely ?

(*d*) Has machine good bearings ?

(*e*) For chucking work, is distance between bearings greater than four times the overhang ?

(*f*) Are all controls handy for operator ?

Coolant.—(*a*) Is pump of robust design and easily accessible ?

(*b*) Can sump be emptied easily ? Has it any nasty corners ?

(*c*) Are distribution fittings robust ?

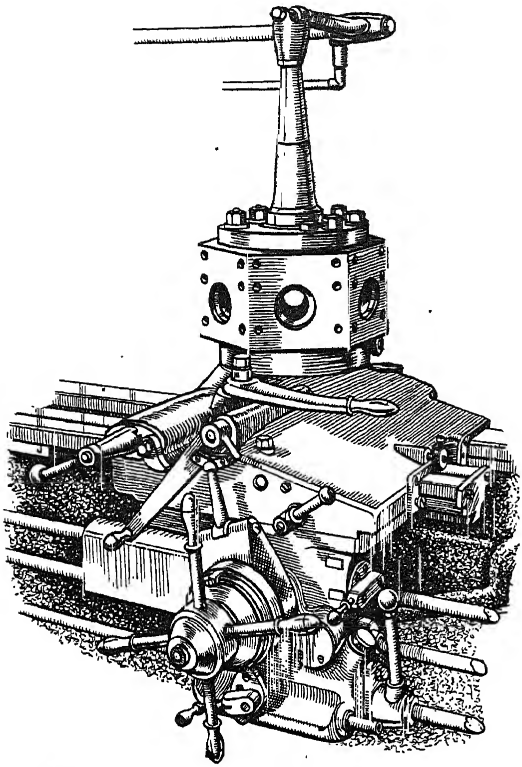


Fig. 2.—The tool head of a turret lathe slides directly on the bed.

Lubrication. — (*a*) Are main gear box and headstock well looked after?

(*b*) Are grease points obvious and easy to reach?

(*c*) Are oil sumps of adequate capacity?

Future.—(*a*) Can increase of cutting speed be accommodated for improved future technique?

(*b*) Is machine versatile enough to suit possible component change?

(*c*) It is better to have a machine slightly larger than necessary to allow for possible component modifications needing increase in bar size.

Installing a Capstan.—*Choosing Site:* Allow ample room for the operator.

Consider position of rod guard (staggered rows).

Allow room to feed rod guard.

Install rack in handy position for storage of bars.

Cleaning.—Before settling down, thoroughly clean all grease, etc., from the ways and handles, and thoroughly oil all points, fill all oil wells and see that all controls are in " neutral."

Levelling.—As capstans and turret lathes are adjusted and tested by the makers with the bed level in both longitudinal and lateral directions, they should be installed similarly to avoid " winding stresses " in the bed. The best plan is to level the machine on three-point support principle with wedges, as shown in Fig. 4. The truth of the bed is checked by spirit level of the precision type of at least 1 ft. in length placed in the positions indicated in Figs. 5, 6, and 7. The wedges must be so adjusted that the levels in all the positions shown are correct, both in a lateral direction at each end of the bed and in a longitudinal direction.

A test piece should be turned, both from the saddle and from the turret, to check accuracy (see Fig. 5).

N.B.—Check oiling before running the machine.

After all tests have proved satisfactory, the machine should be well grouted with a rich cement mixture.

After the cement has set a final tighten should be given to the holding-down bolts.

The machine is then ready for running.

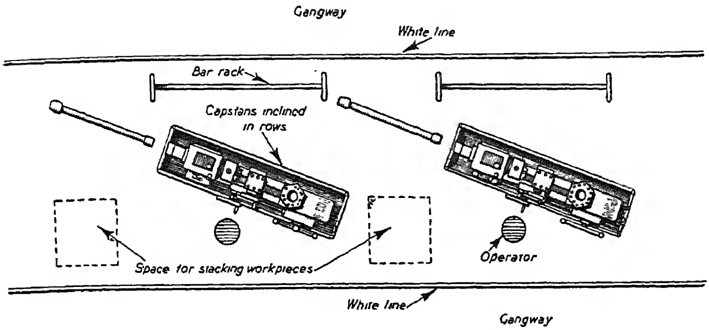


Fig. 3.—Suggested layout for a capstan or turret lathe shop.

Parts of a Capstan (Nos. refer to Fig. 8).—1, Bed; 2, headstock; 3, cross slide; 4, saddle; 5, apron; 6, turret; 7, turret slide and turret ram; 8, star wheel; 9, turret trip; 10, spindle or mandrel; 11, nose; 12, saddle stop; 13, cross stop; 14, turret stop; 15, tool posts; 16, feed box; 17, steady bar; 18, suds pump; 19, sump; 20, chip tray; 21, square tool post.

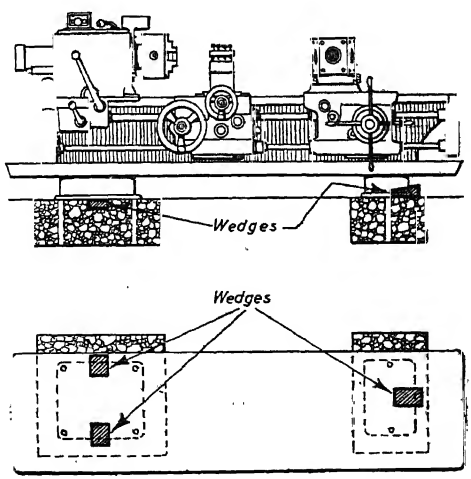


Fig. 4.—Use of wedges for levelling purposes.

Controls of Capstan.—1, Clutch lever; 2, speed-change levers; 3, saddle traverse hand wheel; 4, cross traverse hand wheel; 5, saddle feed lever; 6, cross slide feed lever; 7, saddle feed selector; 8, saddle locking lever; 9, saddle stop adjusting handle; 10, turret feed star wheel; 11, turret feed lever; 12, turret feed selector; 13, turret ram locking lever; 14, turret stop release; 15, coolant adjustment tap; 16, saddle feed lever; 17, saddle stop locking lever; 18, feed drive shaft. (See Fig. 9.)

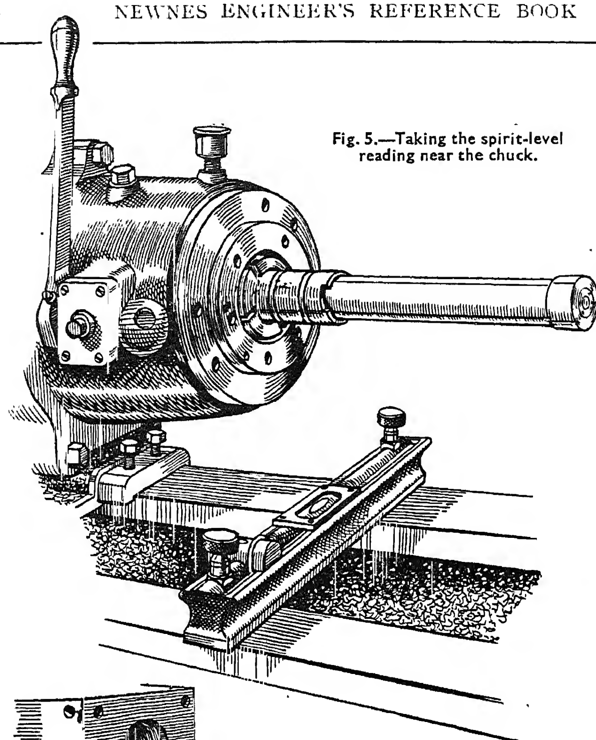


Fig. 5.—Taking the spirit-level reading near the chuck.

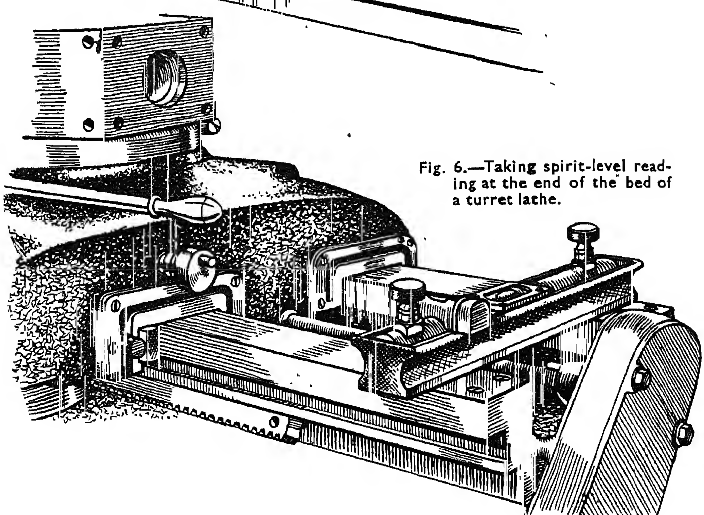


Fig. 6.—Taking spirit-level reading at the end of the bed of a turret lathe.

Parsons .		—	3	0	1	8	$3\frac{11}{16}$	$2\frac{5}{8}$	—	—	—	$12\frac{1}{4}$	3	—	$\frac{3}{4}$	4	—	920	2150	3			Selson M/c Tool Co. Ltd.
Taylor .		1282	6	0	2	4	4	$1\frac{3}{4}$	—	—	—	$5\frac{3}{4}$	3	$1\frac{1}{4}$	$\frac{5}{8}$	6	—	850 1500	1700 3000	2 2	Steel Brass		Chas. Taylor (Birmingham) Ltd.
		1074 $\frac{3}{4}''$	6	3	2	6	5	—	—	—	—	$13\frac{1}{4}$	$3\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{4}$	6	—	540 900	990 1650	3 3	Steel Brass		
		1074 $1\frac{1}{16}''$	6	3	2	6	5	—	—	—	—	12	$3\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{4}$	6	—	308 514	900 1500	3 3	Steel Brass		
		1263	5	9	2	4	4	$1\frac{3}{4}$	—	—	—	$5\frac{3}{4}$	3	$1\frac{3}{16}$	$\frac{5}{8}$	6	—	178	2800	6	—		
Ward .		0	13	6	2	5	4	$1\frac{11}{16}$	$4\frac{1}{2}$	$6\frac{1}{2}$	4	9	$2\frac{3}{4}$	$1\frac{5}{16}$	$\frac{3}{4}$	6	$4\frac{1}{2}$ D	1600 120 200 333	3333 555 925 1541	3 — — —	Brass Reverse 300 Reverse 500 Reverse 833	With 2-speed counter-shaft	H. W. Ward & Co. Ltd.
	E	0E 1	15 13	9 0	2 4	10 0	4 5	$1\frac{11}{16}$ $2\frac{3}{8}$	$4\frac{1}{2}$ 0	$6\frac{1}{2}$ $4\frac{1}{2}$	4 $2\frac{3}{4}$	9 $11\frac{3}{4}$	$2\frac{1}{2}$ $4\frac{5}{8}$	$1\frac{5}{16}$ $1\frac{7}{8}$	$\frac{3}{4}$ 1	6 6	$4\frac{1}{2}$ D $6\frac{3}{8}$ H	480 1028 148 260 455	2850 2900 343 600 1050	4 3 — — —	Elect. rev. Brass Reverse 343 Reverse 600 Reverse 105	With 2-speed counter-shaft	
	E	1A	13	7	3	9	5	$2\frac{3}{8}$	0	$4\frac{1}{2}$	$2\frac{3}{4}$	$11\frac{3}{4}$	5	$1\frac{7}{8}$	1	6	$6\frac{3}{8}$ H	75 200	1650 4130	6 6	Slow range Alt. fast range		
Warner & Swasey	E	1 Elect.	14	2	2	1	$5\frac{1}{2}$	$2\frac{1}{8}$	—	—	$2\frac{3}{8}$	$12\frac{1}{2}$	4	$1\frac{1}{2}$	$\frac{3}{4}$	6	$5\frac{1}{2}$ D	600 600	1800 3600	4 4	— Alt. range		A. C. Wickman Ltd.

E Signifies built-in motor.

CAPACITY OF CAPSTAN LATHES.

(For Mandrel Bore

Machine		*General*			*Saddle*							
Name	*Type*	*Length Overall*	*Width Overall*	*Max. Swing, Radius*	*Max. Swing, Radius*	*Dist. from Nose* *Min.*	*Dist. from Nose* *Max.*	*Feed Min. Max.* *Long*	*Feed Min. Max.* *Cross*	*Dist. from Nose* *Min*	*Dist. from Nose* *Max.*	*Working Stroke*
		ft. in.	*ft. in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
Benrath .	—	7 0	3 4	5½	3¼	—	11¾	HW	HW	—	17	6
Denver E	6R	9 7	4 0	10	5⅞	—	25	·002 ·103	·002 ·103	—	37	14
Drummond E	K	13 3	4 6	7¾	4	3⅜	20¾	·006 ·025	·006 ·025	8¼	29¼	10
Foster E	3	12 0	3 0	7¼	3 1/16	—	9½	8 Feeds	8 Feeds	—	23½	8½
E	5	15 6	4 6	8¾	4¾	—	20¾	·0043 ·0399	·0026 ·0253	—	30	11
E	7	16 0	4 2	10⅜	6¾	—	34½	8 Feeds	8 Feeds	—	40¾	—
Gisholt E	3	17 0	3 8	9¼	4 13/16	—	22	—	—	12½	21½	12
E	4	17 0	3 8	9¼	4 13/16	—	22	—	—	12½	24½	12
E	5	17 0	3 8	9⅞	5 5/16	—	27	—	—	16	30	14
Herbert E	2D	18 8	3 8	5½	2 11/16	—	—	HW	HW	—	18¾	5½
E	4	21 5	4 0	7¼	3⅜	—	—	HW	HW	—	28¼	9
E	4 Senior	21 9	4 2	7¾	3⅞	—	—	·0022 ·033	·0022 ·033	—	30½	9¼
E	4SE	21 9	4 2	8¾	4	—	—	·0022 ·033	·0022 ·033	—	29	9¼
Jones & Lamson E	3	17 0	4 0	10⅝	5½	5½	35¼	·005 ·100	·0025 ·050	6¼	36	10
E	4	17 0	4 0	10⅝	5½	5½	35¼	·005 ·100	·0025 ·050	6¼	36	10
E	5	18 0	4 6	10⅝	6½	5½	35¼	·005 ·100	·0025 ·050	6¼	36	14
Simmons E	2BG	—	—	7	3	—	12	HW	HW	—	18	6
E	2PH	—	—	7	3	—	12	HW	HW	—	18	6

E signifies built-in electric motor. HW signifies hand wheel.

HAND WHEEL OR POWER FEED
see separate Table)

Turret						*Speeds (Spindle)*				
Ht. of Hole Crs. above Slide	*Dia. of Holes in Turret*	*No. of Holes*	*Dia. of Turret (D). A/C Hex. (H)*	*Gain in Stroke Hand Trip*	*Feed Min. and Max.*	*Min. R.P.M.*	*Max. R.P.M.*	*No*	*Remarks*	*Supplied by*
in.	*in.*		*in.*	*in.*	*in.*					
2	1	6	6½ H	2	·006 ·0125	50	1050	6	—	Benrath M/c Tools Ltd.
3¾	2¾	6	13 H	—	·002 ·096	60	600	9	—	Buck & Hickman Ltd.
2 7/16	1½	6	8 1/16 H	1¾	·006 ·025	30	500	8	Std.	Drummond Bros. Ltd.
						60	1000	8	Alternative	
2½	1½	6	8½ H	—	6 Feeds	47	796	—	—	Selson M/c Tool Co. Ltd.
3¼	1½	6	10¼ H	—	·0043 ·0399	41	697	8	—	
						29	505	8	Alt. low range	
						49	818	8	Alt. high range	
—	2	6	12¼ H	—	9 Feeds	32	562	—	—	
4½	1½	6	9¾ H	—	8 Feeds	28	730	6	—	Burton Griffiths & Co. Ltd.
4¾	1½	6	9¾ H	—	8 Feeds	28	730	12	—	
4¾	1¾	6	11 H	—	8 Feeds	28	730	12	—	
1⅞	1	6	—	—	·0018 ·025	50	2550	16	—	Alfred Herbert Ltd.
						28	1400	16	Special	
2⅛	1½	6	—	—	·003 ·025	30	750	8	—	
						15	750	16	With 2-speed motor	
2 7/16	1½	6	—	—	·0022 ·033	40	1000	8	—	
						30	750	8	Special	
						20	1000	16	With 2-speed motor	
						15	750	16	Special 2-speed motor	
2 7/16	1½	6	—	—	·0022 ·033	125	1500	8	—	
3¾	1½	6	9¾ H	—	·005 ·100	20	1000	12	—	Chas. Churchill & Co. Ltd.
						30	1500	12	Alternative	
3¾	1½	6	9¾ H	—	·005 ·100	20	1000	12	—	
						30	1500	12	Alternative	
3¾	2¼	6	10¾ H	—	·005 ·100	20	1000	12	—	
						30	1500	12	Alternative	
2⅝	1	6	7¼ H	—	·004 ·012	188	750		Infinitely variable	Machine Shop Equipment Co. Ltd.
						375	1500			
2⅝	1	6	7¼ H	—	·006 ·018	44	173		Infinitely variable	
						188	750			

H signifies hand.

CAPACITY OF CAPSTAN LATHES.

(For Mandrel Bore

Machine		General					Saddle							
Name	Type	Length Overall		Width Over-all		Max. Swing, Radius	Max. Swing, Radius	Dist. from Nose		Feed Min. Max.		Dist. from Nose		Working Stroke
								Min.	Max.	Long	Cross	Min.	Max.	
		ft.	in.	ft.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Taylor E	1231	8	4	3	0	5	1⅞	—	5	HW	HW	—	12	3½
E	1250	8	8	3	0	6	2⅞	—	7½	HW	HW	—	19¼	6
E	1270	8	8	3	0	6	2⅞	—	7½	HW	HW	—	19¼	6
1199	6″ × 1¼″	9	0	2	6	6	2⅞	—	6	—	HW	—	14¼	6
	6″ × 1½″	9	0	2	6	6	2⅞	—	6	—	HW	—	14¾	6
	7″ × 1¼″	9	6	2	6	7	3 7/16	—	9	—	HW	—	27¼	7½
	7″ × 1½″	9	6	2	6	7	3 7/16	—	9	—	HW	—	26¼	7½
1094	6″ × 1¼″	9	0	2	6	6	3	—	6	HW	HW	—	14¼	6
	6″ × 1½″	9	0	2	6	6	3	—	6	HW	HW	—	14¼	6
	7″ × 1½″	9	6	2	6	7	3⅜	—	9	HW	HW	—	27¼	7½
	7″ × 1¾″	9	6	2	6	7	3⅜	—	9	HW	HW	—	26¼	7½
	1204	9	6	2	6	7	3⅜	—	9	—	HW	—	28½	7½
	1095	9	6	2	6	7	3⅜	—	9	HW	HW	—	21¼	7½
Timbrel & Wright E	2E	8	2	3	9	5½	2¼	—	11	HW	HW	—	12	4
Ward	2	16	0	4	7	5½	2⅝	3	9	HW	HW	7½	15	6
	3	17	2	3	6	6½	3⅜	3	16½	HW	HW	8¾	26	10½ 10
	2A	16	5	5	0	5½	2⅝	3	14¾	HW	HW	7½	19¾	6
	3A	17	2	4	3	6½	3½	3	14	HW	HW	8¾	26	10
	7	12	3	4	3	7⅜	3 11/16	3	22	·005 ·019	·005 ·019	9	31	8
	7 Covered bed	13	6	4	6	8⅛	4¼	3	22	·005 ·019	·005 ·019	11	33	8

E signifies built-in electric motor. **HW** signifies hand wheel.

HAND WHEEL OR POWER FEED—*contd.*

see separate Table)

Turret						*Speeds (Spindle)*				
Ht. of Hole Crs. above Slide	*Dia. of Holes in Turret*	*No. of Holes*	*Dia. of Turret (D). A/C Hex. (H)*	*Gain in Stroke Hand Trip*	*Feed Min. and Max.*	*Min. R.P.M.*	*Max. R.P.M.*	*No.*	*Remarks*	*Supplied by*
in.	*in.*		*in.*	*in.*	*in.*					
1⅜	¾	6	5¼ D	—	H	350	2130	3	2-speed motor	Chas. Taylor (Birmingham) Ltd.
						175	1065	3		
1⅞	1	6	6¼ H	—	H	1000	3000	3	Reverse 2000 3-speed motor	
						500	1500	3	1000	
						250	750	3	500	
1⅞	1	6	6¼ H	—	·0038 ·0086	450	3000	3	Reverse 1160 3-speed motor	
						300	2000	3	775	
						150	1000	3	380	
1⅝	1	6	5¾ D	—	H	234	600	3	Steel	
						390	1000	3	Brass	
1⅝	1	6	5¾ D	—	H	225	575	3	Steel	
						375	960	3	Brass	
2	1¼	6	6⅞ H	—	H	200	540	3	Steel	
						336	900	3	Brass	
2	1¼	6	6⅞ H	—	H	220	450	3	Steel	
						368	750	3	Brass	
1⅝	1	6	5¾ D	—	·0032 ·0072	234	600	3	Steel	
						390	1000	3	Brass	
1⅝	1	6	5¾ D	—	·0032 ·0072	225	575	3	Steel	
						375	960	3	Brass	
2	1¼	6	6⅞ H	—	·0032 ·0072	200	540	3	Steel	
						336	900	3	Brass	
2	1¼	6	6⅞ H	—	·0032 ·0072	220	450	3	Steel	
						308	750	3	Brass	
2	1¼	6	6⅞ H	—	H	176	360	2	Steel	
						294	600	2	Brass	
2	1¼	6	6⅞ H	—	·0032 ·0072	42	500	6	Steel	
						70	834	6	Brass	
2⅛	{1 / 1½	5 / 1}	6¼ H	—	H	350	1740	6	—	Geo. Hatch Ltd.
						460	2090	6	Alternative	
						580	2450	6	Alternative	
1⅞	1	6	6⅝ H	2½	·004 ·0125	800	1972	3	Brass	H. W. Ward & Co. Ltd.
						107	853	6	2-speed countershaft	
2 5/16	1½	6	8⅛ H	3	·004 ·0125	665	1850	3	Brass	
						84	713	6	2-speed countershaft	
1⅞	1	6	6⅝ H	2½	·004 ·0125	48	1020	6	Single pulley	
						71	1531	6	Alt. single pulley	
						95	2041	6	Alt. single pulley	
2 5/16	1½	6	8⅛ H	3	·0024 ·0165	42	825	6	Single pulley	
						59	1155	6	Alt. single pulley	
						84	1650	6	Alt. single pulley	
2⅝	1½	6	8⅛ H	3	·0035 ·080	26	530	8	Single pulley	
						37	750	8	Alt. single pulley	
						50	1000	8	Alt. single pulley	
2⅞	1½	6	8⅛ H	3	·0035 ·080	26	536	8	Single pulley	
						37	750	8	Alt. single pulley	
						50	1000	8	Alt. single pulley	

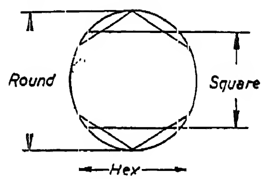
H signifies hand.

CAPACITY OF CAPSTAN LATHES.
(For Mandrel Bore

Machine		*General*			*Saddle*							
Name	*Type*	*Length Overall*	*Width Over-all*	*Max. Swing, Radius*	*Max. Swing Radius*	*Dist. from Nose Min.*	*Dist. from Nose Max.*	*Feed Max. Min. Long*	*Feed Max. Min. Cross*	*Dist. from Nose Min.*	*Dist. from Nose Max.*	*Working Stroke*
		ft. in.	*ft. in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
Warner & Swasey E	2 Elect.	20 3	3 0	7	3	—	12	HW	HW	—	18	6
E	2	15 6	6 8	7	3	—	12	HW	HW	—	18	6
E	3	19 5	3 0	7 11/16	3 1/4	—	19 1/2	·003 ·030	·0025 ·026	—	24	10
E	4	20 2	3 4	9 1/16	4 3/4	—	24 1/2	·003 ·030	·0025 ·026	—	29 3/4	12
E	5	21 5	3 10	10	5 1/8	—	24 1/2	·0045 ·045	·003 ·027	—	34	13

E signifies built-in electric motor. HW signifies hand wheel.

DISTANCE ACROSS FLATS OF HEXAGONS AND SQUARES



Round	*Hexagon*	*Square*	*Round*	*Hexagon*	*Square*
1/4	0·216	0·177	3	2·598	2·121
5/16	0·271	0·221	3 1/8	2·706	2·209
3/8	0·325	0·265	3 1/4	2·814	2·298
7/16	0·379	0·309	3 3/8	2·922	2·386
1/2	0·433	0·353	3 1/2	3·033	2·474
5/8	0·441	0·431	3 5/8	3·141	2·562
3/4	0·649	0·530	3 3/4	3·249	2·651
7/8	0·757	0·618	3 7/8	3·357	2·739
1	0·866	0·707	4	3·464	2·828
1 1/8	0·974	0·795	4 1/8	3·582	2·916
1 1/4	1·082	0·884	4 1/4	3·680	3·005
1 3/8	1·190	0·972	4 3/8	3·788	3·093
1 1/2	1·299	1·060	4 1/2	3·897	3·181
1 5/8	1·407	1·148	4 5/8	4·005	3·269
1 3/4	1·515	1·237	4 3/4	4·113	3·358
1 7/8	1·623	1·325	4 7/8	4·221	3·446
2	1·732	1·414	5	4·330	3·535
2 1/8	1·840	1·502	5 1/8	4·448	3·623
2 1/4	1·948	1·591	5 1/4	4·546	3·712
2 3/8	2·056	1·679	5 3/8	4·654	3·800
2 1/2	2·165	1·767	5 1/2	4·763	3·888
2 5/8	2·273	1·855	5 5/8	4·871	3·976
2 3/4	2·381	1·944	5 3/4	4·979	4·065
2 7/8	2·489	2·032	6	5·196	4·242

HAND WHEEL OR POWER FEED—*contd.*

see separate Table)

Turret						*Speeds (Spindle)*				
Ht. of Hole Crs. above Slide	*Dia. of Holes in Turret*	*No. of Holes*	*Dia. of Turret (D). A/C Hex. (H)*	*Gain in Stroke Hand Trip*	*Feed Max. and Min.*	*Min. R.P.M.*	*Max. R.P.M.*	*No.*	*Remarks*	*Supplied by*
in.	*in.*		*in.*	*in.*	*in.*					
$2\frac{9}{16}$	1	6	$8\frac{1}{2}$ H	—	·003 ·030	600	1800	4	—	A. C. Wickman Ltd.
						600	3600	4	Alternative	
$2\frac{9}{16}$	1	6	$8\frac{1}{2}$ H	—	·003 ·030	67	740	6	—	
$2\frac{7}{8}$	$1\frac{1}{2}$	6	$8\frac{1}{2}$ H	—	·003 ·030	67	740	6	—	
$3\frac{1}{2}$	$1\frac{1}{2}$	6	$9\frac{1}{2}$ H	—	·003 ·030	30	766	12	—	
$3\frac{7}{8}$	$1\frac{3}{4}$	6	11 H	—	·005 ·049	26	658	12	—	

H signifies hand.

HORSE-POWER REQUIRED TO DRIVE TURRET LATHES

Bar Diam. In.	*Horse-power*			*Bar Diam. In.*	*Horse-power*		
	Light Duty	*Medium Duty*	*Heavy Duty*		*Light Duty*	*Medium Duty*	*Heavy Duty*
$\frac{1}{2}$	$\frac{1}{2}$	1	$1\frac{1}{2}$	4	9	11	16
$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	2	$4\frac{1}{2}$	10	12	17
1	1	2	3	5	11	14	18
$1\frac{1}{4}$	$1\frac{1}{2}$	3	4	$5\frac{1}{2}$	12	15	20
$1\frac{1}{2}$	2	$3\frac{1}{2}$	5	6	$12\frac{1}{2}$	16	21
$1\frac{3}{4}$	3	$4\frac{1}{2}$	$6\frac{1}{2}$	$6\frac{1}{2}$	13	17	22
2	4	5	7	7	14	18	23
$2\frac{1}{2}$	5	$6\frac{1}{2}$	9	$7\frac{1}{2}$	15	19	24
3	6	8	11	8	$15\frac{1}{2}$	20	25
$3\frac{1}{2}$	$7\frac{1}{2}$	9	13				

Calculation of Surface Speed.—

D = Diameter of bar (in.).
N = Speed of bar (R.P.M.).
S = Surface speed (ft./min.).

$$S = \frac{\pi DN}{12}$$
$$= 0{\cdot}2618\,DN.$$

Calculation of R.P.M.—

$$N = \frac{12S}{\pi D}$$
$$= 0{\cdot}3280\frac{S}{D}.$$

(See pp. 500–501.)

Machine		*General*					*Saddle*							
Name	*Type*	*O/A Length*	*O/A Width*	*Mandrel Bore*	*Max. Rad. Swing*	*Max. Rad. Swing*	*Cross Traverse In.*	*Long. Traverse In.*	*Cross Feed Max. Min.*	*Cross Feed No.*	*Long. Feed Max. Min.*	*Long. Feed No.*	*Chasing Length*	*Chasing Rge. T.P.I.*
Cincinnati-Acme	E 1	14′	4′ 6″	3	10½	7								
	E 15	11′	4′ 6″	3	13½	9½		41						
	E 2	11′	4′ 6″	3⅝	10½	7	10	41	·002 ·065	12	·001 ·130	12		
	E 3	12′	4′ 6″	3[illegible]	12[illegible]	8[illegible]		52						
	E 35	12′	4′ 6″	4[illegible]	13[illegible]	9[illegible]		56						
	E 17 or 4½	12′	4′ 6″	4[illegible]	12[illegible]	8[illegible]		52						
Herbert	E 7 Jnr.	9′ 4″	4′ 4″	2⅝	8	4		27½	·025 ·002	8	·025 ·002	8	9	4, 8, 16
	E 9B	13′ 9″	6′ 6″	4¼	11¼	6¼		41⅝	·025 ·002	8	·025 ·002	8	15	
	E 9B				15	10½			Otherwise as 9B					
Jones & Lamson	E 7A	10′ 7″	5′ 0″	3	10⅝	6½	14½	42½	·0025 ·050	9	·005 ·100	9	7	4 to 16
	E 7B	10′ 7″	5′ 0″	3	10⅝	6½	14½	39½	·0025 ·050	9	·005 ·100	9	7	4 to 16
	E 7D	10′ 7″	5′ 0″	3	10⅝	9½*			Not Supplied					
	E 8A	10′ 7″	5′ 0″	3½	10⅝	6½	14½	42½	·0025 ·050	9	·005 ·100	9	7	4 to 16
	E 8B	10′ 7″	5′ 0″	3½	10⅝	6½	14½	39½	·0025 ·050	9	·005 ·100	9	7	4 to 16
	E 8D	10′ 7″	5′ 0″	3½	10⅝	9½*			Not Supplied					
									Cross Sliding Head Stock			No. of Stops		
	E 7C	10′ 7″	4′ 5″	3	On ‡ 10⅝	8¾†	8½		·0025 ·050	9		4		
	E 8C	10′ 7″	4′ 5″	3½	10⅝	8¾	8½		·0025 ·050	9		4		
Ward	7	12′ 10″	4′ 6″	2⅝	8	4¾	10½	33	·0035 ·080	10	·0035 ·080	10	21	Any
	E 8	14′ 6″	5′ 0″	3¾	9¾	6¼	14	43	·0035 ·085	10	·0035 ·085	10	30	Any
	E 10	16′ 6″	5′ 9″	4¼	11½	7¾	17	54	·004 ·090	10	·004 ·090	10	38	Any
	E 13	19′ 6″	6′ 6″	8½	14	9⅜	17	80	·0015 ·200	48	·0015 ·200	48	52	Any
	E 16	19′ 6″	7′ 0″	8½	17½	12⅞	23	80	·0015 ·200	48	·0015 ·200	48	52	Any
Warner & Swasey	E 1A	10′ 11″	4′ 9⅝″	3$\frac{1}{16}$	8⅛	6⅝	10⅝	36	·0022 ·073	16	·004 ·149	16	Full length	2⅞–32
	E 2A	17′ 1″	5′ 2″	3½	10	8⅜	12⅝	46	·0022 ·073	16	·004 ·149	16	Full length	2⅞–32
	E 3A	17′ 9¼″	5′ 6½″	4½ or 6	11½	9	13	52⅜	·0025 ·082	16	·005 ·167	16	Full length	2⅞–32
	E 4A	16′ 4″	6′ 11″	8 or 9	14⅛	11$\frac{1}{16}$	16½	58½	·0031 ·1025	16	·005 ·167	16	Full length	2⅞–32

E Denotes built-in electric motor. * Way covers.

Turret									Spindle Speed R.P.M.				
Max. Dist. from Nose In.	A/F In.	Dia. of Hole In.	Long. Feed Max. Min.	Long. Feed No.	Power Traverse Ft./Min.	Cross Movement of Hex. Turret Trav. In.	Cross Movement of Hex. Turret Feed Max. Min.	Cross Movement of Hex. Turret Feed No.	Max.	Min.	No.	Remarks	Supplied By
39 53 53	 16½ 16½	 3[illegible] 3[illegible]	 ·004 ·130	 12	Can be Supplied	8	·002 ·065	12	500 500 500	15 15 15	12 12 12		Buck & Hickman Ltd.
62 65 62	19 19 19	6¼ 6[illegible] 6[illegible]			Can be Supplied				266 266 266	8 8 8	9 9 9		
40	12½	2⅛	·025 ·002	8	Not Supplied				750	30	8		Alfred Herbert Ltd.
60	14⅜	3 5/16	·025 ·002	8	Not Supplied				403	14	16	9B Special Order	
52	14	3⅛	·005 ·100	9	50 12½	Not Supplied			1000 1500	20 30	12 12	Special Order 5″ Mandrel Bore can be Supplied	Chas. Churchill & Co. Ltd.
49	14	3⅛	·005 ·100	9	50 12½	7½	·0025 ·050	9	1000 1500	20 30	12 12	,,	
51	Flat Turret 16″ dia.	3″ below ‡	·005 ·100	9	50 12½	Not Supplied			1000 1500	20 30	12 12	,,	
52	14	3⅝	·005 ·100	9	50 12½				1000 1500	20 30	12 12	,,	
49	14	3⅝	·005 ·100	9	50 12½	7½	·0025 ·050	9	1000 1500	20 30	12 12	,,	
51	Flat Turret 16″ dia.	3″ below ‡	·005 ·100	9	50 12½	Not Supplied			1000 1500	20 20	12 12	,,	
52	Flat Turret 16″ dia.		·005 ·100	9	Not Supplied				1000	20	12		
52	16″ dia.		·005 ·100	9					1000	20	12		
43	11½	2⅛	·0035 ·080	10	25	Not Supplied			536 750 1000	26 37 50	8 8 8	Single Pulley or Built-in Motor	H. W. Ward & Co. Ltd.
55½	14	3¼	·0035 ·085	10	25	Not Supplied			600 800	15 20	16 16	Alt.	
66	15¼	3¼	·004 ·090	10	25	Not Supplied			470 580	16 19	16 16	Alt.	
99	20	5	·0015 ·200	48	25	Not Supplied			225	7	16		
99	20	5	·0015 ·200	48	25	Not Supplied			225	7	16		
43½	13½	2¾	·004 ·149	16	36	Can be Supplied			458	20	12		A. C. Wickman Ltd.
51½	15¼	3¾	·004 ·149	16	37½	Can be Supplied			460	17	12		
58½	17¼	5	·005 ·167	16	40	Can be Supplied			314	12	12		
68¾	20¼	6¼	·005 ·167	16	36¼	Can be Supplied			212	8	12		

† Head over to stop. ‡ Denotes centre line.

CAPACITY OF PITTLER

Data supplied by

Model No.	Overall Dimensions Length ft. in.	Overall Dimensions Width ft. in.	Centre Ht.	Principal Dimensions, in. Nose to Turret Face Max.	Collet Chuck Turret Face Max.	Length of Bed	Length Turned with Cross Slide	Spindle Bore	Max. Bar Dia. Admitted	Capacity, in. Max. Dia. Turned Chuck Work	Max. Swing over Bed Without Chasing Arm	Max. Swing over Bed With Chasing Arm
RC II 36 D	5 10	2 8	5 11/16	15 3/4	11	56 3/4	Not fitted	1 21/64	1 5/16	4 3/8 7 1/8*	14 1/2	11 5/8
RD II 47 D	7 5	3 0	7 9/32	22	17 3/4	69	Not fitted	1 27/32	1 3/4	5 1/16 8 11/16*	17 1/2	12 1/4
RE II 60 D	9 11	3 6	8 21/32	29 1/2	24	86	11 3/4	2 23/64	2 1/4	6 3/4 11* 16 7/8†	21 5/8	13 1/2
RF II 60 D	11 0	3 10	9 5/8	35 1/2	29 1/2	98 1/2	14 3/4	2 23/64	2 1/4	11 3/4* 7 7/16 19 3/4†	24 5/8	16 7/8
RG II 82 D	11 0	3 10	9 5/8	34 1/2	27 1/2	98 1/2	13 3/4	3 15/64	3 1/8	7 7/16 11 [illegible]* 19 [illegible]†	24 5/8	18 7/8
RH II 105 D	11 0	3 10	9 5/8	35 1/2	26 3/4	98 1/2	13	4 9/64	4	7 [illegible] 11 [illegible]* 19 [illegible]†	24 5/8	18 7/8
RB II 28	5 3	2 6	4 21/32	11 3/4	9 1/8	39 5/8	Not fitted	1 5/64	1 1/32	3 9/16 4 3/8*	13 3/8	8 7/8
RB II 36	5 3	2 6	4 25/32	11 3/4	9 7/8	39 5/8	Not fitted	1 27/64	1 5/16	3 9/16 4 3/4*	13 3/8	8 7/8
RD II 47 S	7 5	3 0	7 9/32	24 5/8	19 5/8	69	Not fitted	1 27/32	1 3/4	5 1/16 8 5/8*	17 1/2	12 1/4
RE II 60 S	9 9	3 2	8 21/32	31 1/2	25 5/8	86	Not fitted	2 23/64	2 1/4	6 3/4 11*	21 5/8	14 3/8

* On work necessitating only a few tools. † With cross slide.

MANDREL CAPACITIES OF CAPSTAN LATHES

Name	Type and Capacity
Brown & Sharpe	0, 3/8″; 1, 5/8″; 2, 1″.
Drummond	K, 1 5/8″.
Exacta	RO, 5/8″.
Foster	1, 13/16″; 3, 1 5/16″; 5, 2″; 7, 2 9/16″.
Gisholt	3, 1 1/2″; 4, 2″; 5, 2 1/2″.
Herbert	0, 1/2″; 1, 3/4″; 2S, 1 1/4″; 2D, 1 1/4″; 2B, 1 1/4″; 2ND, 1 1/4″; 3, 1 5/8″; 4, 1 5/8″; 4 Senr., 1 5/8″; 4SE, 1 1/2″.
Jones & Lamson	3, 1 1/2″; 4, 1 3/4″; 5, 2 1/2″.
Murad	3/4, 3/4″.
Parsons	1/2″.

TURRET LATHES

Pittler, Leipzig

Turret Head.						Spindle Speeds R.P.M.			Turret Feed. in./rev.						
				Tool Holes					Long			Lateral			Cross-slide Feeds
Dia. Face Plate	Dia. Jaw Chuck	Dia.	Dia. Tool-hole Circle	No.	Dia.	No.	Max.	Min.	No.	Max.	Min.	No.	Max.	Min.	
		in.	in.		mm.										
9⅞	5⅛	8½	5⅞	7 6 3	15 30 35‡	24	1500	53	6	·02	·0026	6	·0134	·0017	—
11¾	6 9/32	10½	7½	6 6 4	15 30 38‡	8	990	37	8	·0256	·0025	8	·0189	·0018	—
13¾	9	13¼	9	6 6 4	20 40 50‡	32	750	15	10	·035	·0022	10	·0287	·0018	Same as Turret
16⅞	10⅝	15⅛	10⅝	6 6 4	20 40 65‡	16	600	20	8	·0327	·0022	8	·0244	·0017	Same as Turret
18¾	15	15 5/32	10⅝	6 6 4	20 40 65‡	16	480	15	8	·0327	·0022	8	·0244	·0017	Same as Turret
18¾	15	15 5/32	10⅝	6 6 4	20 40 45‡	16	380	12	8	·0327	·0022	8	·0244	·0017	Same as Turret
—	4 5/16	7⅞	5 5/16	5 7	15 30	8	4200	375	3	·0035	·0011	—	—	—	—
—	4 5/16	7⅞	5 5/16	5 7	15 30	8	3500	310	3	·0035	·0011	—	—	—	—
—	6⅞	10½	7½	6 6 4	15 30 38‡	8	3000	175	8	·0126	·0012	8	·0094	·0009	—
—	7⅞	13¼	9	6 6 4	20 40 50‡	8	2000	175	10	·0174	·0011	10	·0143	·0009	—

‡ 2 of which are merged into one elongated hole.

MANDREL CAPACITIES OF CAPSTAN LATHES (*cont.*)

Name	*Type and Capacity*
Pultra . . .	335/8, 5 mm.; 355/8, 7 mm.
Simmons . .	2, 1¼″.
Taylor . . .	1263, ½″; 1231, 1 1/16″; 1250, 1¼″; 1270, 1¼″; 1220, 1½″; 1282, ½″; 1074, ¾″ or 1074, 1 1/16″.; 1199, 1¼″, 1½″ or 1¾″; 1094, 1¼″, 1½″ or 1¾″; 1204, 2½″; 1095, 1½″.
Timbrell & Wright .	2E, 1″.
Ward . . .	0, ½″ or ⅞″ (without wire feed); 1, 1″; 2, 1¼″; 3, 1½″; 0E, ½″; 0E (without wire feed), ⅞″; 1A, 1″; 2A, 1¼″; 3A, 1½″; 7, 2⅛″; 7 (covered bed), 2⅛″.
Warner & Swasey .	1, ⅝″; 2, 1″; 3, 1½″; 4, 2″; 5, 2½″.

CUTTING SPEED IN R.P.M. FOR REQUIRED SURFACE SPEED

Bar Dia.	*Surface Speed in ft./min.*											*Bar Dia.*
In.	30	40	50	60	70	80	90	100	120	140	160	*In.*
1/16	1833	2444	3056	3668	4280	4888	—	—	—	—	—	1/16
1/8	916	1222	1528	1834	2140	2444	2752	3056	3668	4278	4890	1/8
3/16	687	917	1146	1375	1605	1833	2064	2292	2751	3207	3667	3/16
1/4	458	611	764	917	1070	1222	1376	1528	1834	2139	2445	1/4
5/16	367	489	611	733	856	978	1100	1222	1466	1711	1955	5/16
3/8	306	408	560	611	713	815	916	1018	1222	1425	1629	3/8
1/2	229	306	382	459	535	611	688	764	917	1070	1222	1/2
5/8	184	245	306	367	428	489	552	612	736	857	979	5/8
3/4	153	203	254	306	357	408	458	508	610	711	813	3/4
7/8	131	175	219	262	306	349	392	438	526	613	701	7/8
1	115	153	191	229	267	306	344	382	458	533	611	1
1 1/8	102	136	170	204	238	272	306	340	408	476	544	1 1/8
1 1/4	91·6	123	153	183	214	245	274	306	367	428	490	1 1/4
1 3/8	83·3	111	139	167	195	222	250	278	334	389	445	1 3/8
1 1/2	76·3	102	127	153	178	204	230	254	305	356	406	1 1/2
1 5/8	70·5	93·9	117	141	165	188	212	234	281	328	374	1 5/8
1 3/4	65·5	87·3	109	131	153	175	196	218	262	305	349	1 3/4
1 7/8	61·1	81·5	102	122	143	163	184	204	244	286	326	1 7/8
2	57·3	76·4	95·5	115	134	153	172	191	229	267	306	2
2 1/8	54·0	72·0	90·0	108	126	144	162	180	216	252	288	2 1/8
2 1/4	51·0	68·0	85·5	102	119	136	153	170	204	238	273	2 1/4
2 3/8	48·3	64·4	80·5	96·6	113	129	145	161	193	225	258	2 3/8
2 1/2	45·8	61·2	76·3	91·7	107	122	138	153	184	213	245	2 1/2
2 5/8	43·5	58·0	72·5	87·0	102	116	131	145	174	203	232	2 5/8
2 3/4	41·7	55·6	69·5	83·4	97·2	111	125	139	167	195	222	2 3/4
2 7/8	39·6	52·8	66·0	79·2	92·4	106	119	132	158	185	211	2 7/8
3	38·2	51·0	63·7	76·4	89·1	102	114	127	152	178	203	3
3 1/4	35·1	46·8	58·5	70·2	81·9	93·6	105	117	140	171	188	3 1/4
3 1/2	32·7	43·6	54·5	65·5	76·4	87·4	98·1	109	131	164	174	3 1/2
3 3/4	30·6	40·8	51·0	61·2	71·4	81·6	91·8	102	122	153	163	3 3/4
4	28·7	38·2	47·8	57·3	66·9	76·4	86·1	95·6	115	134	153	4
4 1/4	26·9	35·9	44·9	53·9	62·9	71·8	80·8	89·8	108	126	144	4 1/4
4 1/2	25·4	34·0	42·4	51·0	59·4	67·9	76·3	84·8	102	119	136	4 1/2
4 3/4	24·1	32·2	40·2	48·2	56·3	64·3	72·4	80·4	96·9	113	129	4 3/4
5	22·9	30·6	38·2	45·9	53·5	61·1	68·8	76·4	91·7	107	122	5
5 1/4	21·8	29·1	36·4	43·6	50·9	58·2	65·4	72·7	87·2	102	116	5 1/4
5 1/2	20·8	27·8	34·7	41·7	48·6	55·6	62·5	69·4	83·3	97·2	111	5 1/2
5 3/4	19·9	26·6	33·2	39·8	46·5	53·1	59·8	66·4	80·0	93·0	106	5 3/4
6	19·1	25·3	31·8	38·2	44·6	51·0	57·2	63·6	76·3	89·0	102	6
6 1/4	18·3	24·4	30·6	36·7	42·8	48·9	55·0	61·1	73·3	85·5	97·7	6 1/4
6 1/2	17·6	23·5	29·4	35·2	41·1	47·0	52·8	58·7	70·4	82·2	93·9	6 1/2
6 3/4	17·0	22·6	28·3	34·0	39·6	45·3	50·9	56·6	67·9	79·2	90·6	6 3/4
7	16·4	21·8	27·3	32·7	38·2	43·7	49·0	54·6	65·5	76·4	87·4	7
7 1/2	15·3	20·4	25·1	30·5	35·6	40·7	45·8	50·9	61·1	71·0	81·4	7 1/2
8	14·3	19·1	23·9	28·7	33·4	38·2	43·0	47·8	57·4	66·9	76·5	8
8 1/2	13·5	17·9	22·5	16·9	31·5	35·9	40·4	44·9	54·0	63·0	71·8	8 1/2
9	12·7	17·0	21·2	25·5	29·7	33·9	38·2	42·4	51·0	59·5	67·8	9
9 1/2	12·1	16·1	20·1	24·1	28·2	32·2	36·2	40·2	48·3	56·4	64·4	9 1/2
10	11·5	15·3	19·1	22·9	26·8	30·6	34·4	38·2	45·8	53·5	61·2	10

CUTTING SPEED IN R.P.M. FOR REQUIRED SURFACE SPEED

Bar Dia.	*Surface Speed in ft./min.*											*Bar Dia.*
In.	180	200	250	300	400	500	600	700	800	900	1000	*In.*
1/16	—	—	—	—	—	—	—	—	—	—	—	1/16
1/8	—	—	—	—	—	—	—	—	—	—	—	1/8
3/16	4125	4584	—	—	—	—	—	—	—	—	—	3/16
1/4	2750	3056	3810	4584	—	—	—	—	—	—	—	1/4
5/16	2200	2444	3055	3666	4888	—	—	—	—	—	—	5/16
3/8	1832	2036	2596	3054	4072	5192	—	—	—	—	—	3/8
1/2	1375	1528	1910	2292	3056	3820	4584	—	—	—	—	1/2
5/8	1102	1224	1530	1836	2448	3060	3672	4284	4896	—	—	5/8
3/4	914	1016	1270	1524	2032	2540	3048	3556	4074	4582	5080	3/4
7/8	788	876	1095	1314	1752	2190	2628	3166	3504	3942	4380	7/8
1	688	764	955	1146	1528	1910	2292	2674	3056	3438	3820	1
1 1/8	612	680	850	1020	1360	1700	2040	2380	2720	3060	3400	1 1/8
1 1/4	551	612	765	918	1224	1530	1836	2146	2448	2754	3060	1 1/4
1 3/8	500	556	695	834	1112	1390	1668	1946	2224	2502	2780	1 3/8
1 1/2	457	508	635	762	1017	1270	1524	1778	2035	2289	2540	1 1/2
1 5/8	421	468	585	702	937	1170	1404	1638	1875	2109	2340	1 5/8
1 3/4	392	436	545	654	872	1090	1308	1526	1745	1963	2180	1 3/4
1 7/8	367	408	510	612	816	1020	1224	1428	1632	1836	2040	1 7/8
2	344	382	477	573	763	954	1146	1337	1535	1726	1908	2
2 1/8	324	360	450	540	720	900	1080	1260	1440	1620	1800	2 1/8
2 1/4	306	340	425	510	680	850	1020	1190	1360	1530	1700	2 1/4
2 3/8	290	322	402	483	644	804	966	1127	1288	1449	1608	2 3/8
2 1/2	275	306	382	459	612	764	918	1071	1215	1368	1528	2 1/2
2 5/8	261	290	362	435	580	724	870	1015	1160	1305	1448	2 5/8
2 3/4	250	278	347	417	556	694	834	973	1112	1251	1388	2 3/4
2 7/8	238	264	330	396	528	660	792	924	1056	1188	1320	2 7/8
3	228	254	318	381	508	636	762	889	1016	1143	1272	3
3 1/4	211	234	292	351	468	584	702	819	936	1053	1168	3 1/4
3 1/2	196	218	272	327	436	544	654	763	874	983	1088	3 1/2
3 3/4	184	205	256	307	410	512	615	717	816	918	1024	3 3/4
4	172	191	239	286	382	478	573	667	764	854	956	4
4 1/4	162	180	225	270	360	450	540	630	718	808	900	4 1/4
4 1/2	153	170	212	255	340	424	510	595	679	764	848	4 1/2
4 3/4	145	161	201	241	322	402	483	563	643	723	804	4 3/4
5	138	153	191	229	306	382	459	515	611	687	764	5
5 1/4	131	145	181	218	290	362	435	508	582	655	721	5 1/4
5 1/2	125	139	174	208	278	348	417	486	556	625	694	5 1/2
5 3/4	120	133	166	199	266	332	399	465	531	597	664	5 3/4
6	114	127	159	191	254	318	381	445	510	574	636	6
6 1/4	110	122	153	183	244	306	366	427	489	550	611	6 1/4
6 1/2	106	117	146	176	234	292	351	410	470	529	587	6 1/2
6 3/4	102	113	141	170	226	282	339	396	453	510	566	6 3/4
7	98·3	109	136	164	218	272	327	382	437	492	546	7
7 1/2	91·6	102	127	153	204	254	306	357	407	458	509	7 1/2
8	86·0	95·6	120	143	191	240	287	335	382	430	478	8
8 1/2	80·8	89·8	112	135	180	224	269	314	359	404	444	8 1/2
9	76·4	84·8	106	127	170	212	255	297	339	381	424	9
9 1/2	72·4	80·4	101	120	161	202	241	281	322	362	402	9 1/2
10	68·8	76·2	95·3	114	152	191	229	267	306	344	382	10

TURNING SPEEDS FOR TUNGSTEN-CARBIDE TIPPED TOOLS. FOR VARIOUS MATERIALS
Tipping Material, Wimet. Data supplied by A. C. Wickman Ltd.

Grades of Steel	*Grade of Wimet*	*Rough Turning ft./min.*	*Finish Turning ft./min.*	*Top Rake Rough*	*Top Rake Finish*	*Depth of Cut*	*Rough Feed*	*Finish Feed*
				°	°	*in.*	*in.*	*in.*
28–35 tons tensile:								
Black bar stampings	S58	100–200	200–250	15	15	¼	·078	·010
	X8	250–300	300–500	8	10	¼	·040	·008
	XX	350–400	600–800	Up to 15	Up to 10	3/16	·010	·003
Rough forgings: removing scale	S58	100–150	150–250	15	15	¼	·060	·010
	X8	200–250	300–500	8	10	¼	·030	·008
	XX	300–350	600–800	8	10	3/16	·010	·003
Clean metal	S58	180–250	250–300	Up to 20	20	¼	·080	·010
	X8	280–380	400–500	8	8	¼	·040	·008
	XX	400–600	600–800	10	8	3/16	·012	·005
Castings	S58	140–200	180–250	15	10	¼	·050	·008
	X8	200–250	250–350	8	8	¼	·030	·008
	XX	250–300	500–750	8	10	3/16	·010	·003
40–45 tons tensile:								
Black bar stampings	S58	120–150	150–200	15–18	10	¼	·070	·010
	X8	200–250	300–400	8	8	¼	·040	·008
	XX	250–350	500–600	10	8	3/16	·010	·004
Rough forgings: removing scale	S58	120–135	135–190	15	12	¼	·050	·010
	X8	200–250	300–480	8	8	¼	·038	·008
	XX	250–300	500–600	8	10	3/16	·010	·005
Clean metal	S58	120–150	180–220	15	12	¼	·050	·010
	X8	200–300	300–500	8	8	¼	·030	·008
	XX	300–600	500–600	8	8	3/16	·010	·005
Castings	S58	120–180	160–220	15	15	¼	·040	·015
	X8	180–220	220–300	8	8	¼	·028	·010
	XX	250–350	350–500	5	8	3/16	·010	·005
55–65 tons tensile:								
Black bar stampings	S58	80–100	100–120	10	10	⅛–¼	·032	·005
	X8	150–190	200–250	8	8	¼	·015	·008
	XX	200–300	350–450	8	10	¼	·006	·008
Rough forgings: removing scale	S58	70–90	100–150	12	10	¼	·020	·008
	X8	120–150	200–300	8	8	¼	·010	·008
	XX	200–275	400–500	5	5	3/16	·008	·005
Clean metal	S58	80–100	120–150	15	15	¼	·030	·010
	X8	120–180	160–220	8	8	¼	·010	·008
	XX	300–500	400–500	5	8	3/16	·008	·005
High-speed steel annealed	S58	60–82	80–100	10	10	Up to ⅜	·040	·010
	X8	90–150	150–200	5	8	¼	·010	·005
	XX	150–200	200–250	5	5	3/16	·008	·003
Chrome nickel—65–95 tons tensile:								
Black bar stampings	S58	60–92	90–100	10	10	Up to ½	·030	·010
	X8	80–100	100–120	5	8	¼	·015	·008
	XX	200–250	300–400	5	5	3/16	·008	·005
Forgings	S58	60–90	90–100	10	10	¼	·030	·010
	X8	90–100	100–150	5	5	¼	·010	·008
	XX	175–225	300–400	5	8	3/16	·008	·003
Clean metal	S58	90–110	100–150	12	12	¼	·038	·015
	X8	120–150	150–220	8	8	¼	·015	·008
	XX	250–350	300–400	5	5	3/16	·008	·005
Stainless steel:								
Castings	S58	50–90	90–110	10	10	¼	·025	·015
	X8	65–100	100–180	8	8	¼	·015	·008
	XX	90–125	125–200	3	5	3/16	·008	·005
Bar	S58	100–120	120–140	10	10	¼	·030	·010
	X8	110–150	150–210	5	8	¼	·018	·008
	XX	200–250	250–300	3	5	3/16	·009	·003
Manganese steel, 12 per cent.[1]	S58	10–20	20–30	8	8	Depends on conditions but may be ⅛	·020	·010
	X8	10–25	25–30	3	3		·010	·005
	XX	10–25	25–40	0	0–3		·008	·003

[1] Owing to work hardening, a continuous cut is advised, with a fairly heavy feed.

TURNING SPEEDS FOR TUNGSTEN-CARBIDE TIPPED TOOLS—*cont.*

Cast Iron and Non-ferrous Materials	*Grade of Wimet*	*Rough Turning ft./min.*	*Finish Turning ft./min.*	*Top Rake Rough*	*Top Rake Finish*	*Depth of Cut*	*Rough Feed*	*Finish Feed*
				°	°	*in.*	*in.*	*in.*
Cast iron, 200B	N	185–200	300–425	8	8	$\frac{1}{4}$	Up to ·020	Up to ·010
Close-grained iron	N or H	160–200	250–400	3	3	$\frac{1}{4}$	·012	·008
Centrifugal castings	N or H	135–180	250–325	3	3	$\frac{1}{4}$	·010	·005
Chromium iron	N or H	130–180	250–325	3	3	$\frac{1}{4}$	·010	·005
Malleable iron	N or H	165–210	300–425	8	8	$\frac{1}{4}$	·012	·008
10 per cent. nickel iron	H	20–35	25–45	0–2 Neg.	0	Up to $\frac{3}{16}$	·008–·010	·004
Pearlite iron	H	20–30	25–45	0–2 Neg.	0	Up to $\frac{3}{16}$	·008–·010	·004
Wrought iron	N or H	150–200	250–300	3	8	$\frac{1}{4}$	·010–·015	·008
Copper	N	500–800	750–1000	13	13	$\frac{1}{4}$	$\frac{1}{32}$	Up to ·012
Cupro-nickel	N or H	350–500	400–600	8	8	$\frac{1}{4}$	·020	Up to ·012
Soft brass	N	750–1000	750–1000	3	3	$\frac{1}{4}$	$\frac{1}{32}$	Up to ·015
Hard cast brass	H	400–600	500–800	3	3	$\frac{3}{16}$	·020	Up to ·012
Bronze	N or H	400–600	500–800	3	3	$\frac{3}{16}$	·020	·012
Gunmetal	N or H	400–600	500–800	3	3	$\frac{3}{16}$	·015–·020	·012
Aluminium bronze	N or H	350–600	500–800	3	3	$\frac{3}{16}$	·012–·018	·010
Admiralty bronze	N or H	400–600	500–800	3	3	$\frac{1}{4}$	·015–·020	·012
Manganese bronze	N or H	350–400	450–650	3	3	$\frac{1}{4}$	·012–·018	·010
Aluminium	X	Up to 7000	Up to 7000	20	Up to 15	Up to $\frac{1}{2}$	Up to ·012	·004
Silicon aluminium	X	400–550	500–750	13	13	Up to $\frac{3}{16}$	·008	·004
Aluminium alloys	X	500–800	700–1000	13	13	Up to [illegible]	·008	·003
Zinc-base alloys	N	600–800	800–1000	13	13	Up to [illegible]	·005	·003
Duralumin	N or H	600–800	800–1000	13	13	Up to [illegible]	·012	·005
Plastics	N or H	300–600	300–600	0–8	0–8	$\frac{1}{8}$–$\frac{3}{16}$	·006	·003 [1]
Erinoid	N or H	300–600	300–600	0–8	0–8	$\frac{1}{8}$–$\frac{3}{16}$	·006	·003 [1]
Ebonite	N or H	200–500	200–500	0	0	$\frac{1}{8}$–$\frac{3}{16}$	·006	·003 [1]
Glass	N or H	40–60	40–60	0–3	0–3	—	Hand feed recommended	
Slate	N or H	60–80	60–80	0–3	0–3	—	Hand feed recommended	
Marble	N or H	60–80	60–80	0–3	0–3	—	Hand feed recommended	
Hard rubber	N or H	600–800	600–800	0–8	0–8	$\frac{1}{16}$	·012	·008

[1] Heavy feeds are not recommended owing to liability of material cracking. When drilling, peripheral speed of drill should be generally two-thirds of the above.

	Grade of Wimet	*Feet per minute*	*Feed*	*Depth of Cut*	*Top Rake*	*Clearance*
			in.	*in.*	°	°
Medium rubber	N or H	400	·002–·016	·003–·125	45	5

	Grade of Wimet	*Shore Hardness*	*Rough Turning*		*Finish Turning*	
			Speeds ft./min.	*Feeds*	*Speeds ft./min.*	*Feeds*
Chilled iron rolls	H	55–65	11–15	2 mm.	20	4 mm.
		70–75	7–10	2 mm.	15	3 mm.
		80–90	3–6	1 mm.	10	2 mm.

The clearance angles should be 4–6° with the exception of plastic materials, which should be from 6 to 10°. For chilled iron rolls, clearance angles should be from 2° to 4°.

Width of Parting-off Tool

Diam. of Bar In.	*Non-ferrous Materials*	*Mild Steel or Cast Iron*	*Alloy Steel*	*Diam. of Bar In.*	*Non-ferrous Materials*	*Mild Steel or Cast Iron*	*Alloy Steel*
1/16	0·032	0·033	0·034	3/4	0·100	0·118	0·132
3/32	0·034	0·037	0·038	7/8	0·112	0·134	0·150
1/8	0·037	0·041	0·043	1	0·125	0·150	0·168
5/32	0·041	0·044	0·047	1 1/8	0·137	0·166	0·186
3/16	0·044	0·048	0·052	1 1/4	0·150	0·180	0·204
1/4	0·050	0·057	0·061	1 3/8	0·162	0·197	0·221
5/16	0·056	0·064	0·069	1 1/2	0·175	0·212	0·239
3/8	0·062	0·072	0·078	1 5/8	0·187	0·228	0·257
7/16	0·069	0·080	0·087	1 3/4	0·200	0·244	0·275
[illegible]	0·075	0·087	0·096	2	0·225	0·275	0·310
[illegible]	0·087	0·103	0·114				

Cutting Speed and Feed for High-speed Steel Tools

Material	*Surface Speed, ft./min.*		*Feed, in./rev.*		
	Rough	*Finish*	*Rough*	*Finish*	*Forming*
Mild steel or machine steel, Soft	80–90	90–100	0·020–0·030	0·010–0·020	0·001–0·005
Mild steel or machine steel, Medium	60–70	70–90	0·020–0·030	0·010–0·020	0·001–0·005
Mild steel or machine steel, Hard	40–50	45–55	0·015–0·030	0·008–0·015	0·001–0·005
Cast steel, Annealed	60–70	60–70	0·020–0·030	0·005–0·008	0·001–0·004
Alloy steel	40–45	45–50	0·010–0·020	0·005–0·012	0·001–0·003
Cast iron, Soft Grey	50–60	60–75	0·031–0·062	0·020–0·040	0·003–0·010
Cast iron, Hard	35–45	50–70	0·031–0·062	0·020–0·040	0·003–0·010
Steel castings	50–55	55–60	0·010–0·025	0·003–0·010	0·001–0·005
Brass, Cast	200–250	200–250	0·062–0·080	0·032–0·062	0·002–0·010
Brass, Soft	200–300	230–300	0·050–0·070	0·032–0·062	0·002–0·008
Bronze, Aluminium	90–100	100–120	0·012–0·018	0·008–0·010	0·002–0·008
Bronze, Admiralty	90–150	90–150	0·015–0·020	0·010–0·012	0·003–0·010
Bronze, Hard	80–90	80–100	0·012–0·018	0·008–0·010	0·002–0·008
Aluminium	300–500	300–500	0·005–0·015	0·008–0·010	0·001–0·003
Aluminium alloy	200–400	200–400	0·005–0·015	0·008–0·010	0·001–0·003
Plastics [1]	200–300	200–300	0·003–0·005	0·002–0·004	0·001–0·002
Ebonite [1]	100–200	100–200	0·003–0·005	0·002–0·004	0·001–0·002

[1] For plastics and ebonite, best results are obtained with deep cut and very fine feed.

NUMBER OF COMPONENTS THAT CAN BE OBTAINED FROM ONE BAR [1]

Length of Component	*No Scrap Allowance*				*5 per cent. Scrap Allowance*				*10 per cent. Scrap Allowance*			
	Length of Bar, ft.				*Length of Bar, ft.*				*Length of Bar, ft.*			
In.	8	10	12	14	8	10	12	14	8	10	12	14
$\frac{1}{8}$	376	472	571	667	356	448	541	633	338	424	513	594
$\frac{3}{16}$	303	380	456	537	287	360	434	509	272	344	410	482
$\frac{1}{4}$	252	313	380	444	239	297	361	420	226	281	342	399
$\frac{5}{16}$	216	270	325	380	205	267	368	360	194	243	292	342
$\frac{3}{8}$	188	236	284	332	179	224	270	316	169	212	256	299
$\frac{1}{2}$	150	189	227	266	143	179	216	253	135	170	204	249
$\frac{5}{8}$	125	157	189	221	119	149	180	200	102	141	170	189
$\frac{3}{4}$	107	134	162	189	101	128	154	180	95	121	146	170
$\frac{7}{8}$	93	117	141	165	88	111	134	157	84	105	127	148
1	83	104	125	147	79	99	119	139	74	94	113	132
$1\frac{1}{8}$	74	93	113	132	70	89	107	126	67	84	101	119
$1\frac{1}{4}$	67	85	102	117	63	81	97	111	60	76	92	105
$1\frac{3}{8}$	62	77	94	110	58	74	89	104	55	70	84	99
$1\frac{1}{2}$	57	71	86	101	54	68	82	96	51	64	78	91
$1\frac{5}{8}$	53	66	80	94	50	63	76	89	47	60	72	84
$1\frac{3}{4}$	49	62	75	88	47	59	71	83	43	56	67	79
$1\frac{7}{8}$	45	58	70	82	43	55	67	78	41	52	63	74
2	43	55	66	77	41	52	63	73	39	49	59	69
$2\frac{1}{8}$	42	51	62	73	40	49	59	69	38	46	56	65
$2\frac{1}{4}$	39	49	59	69	37	46	56	66	35	44	53	62
$2\frac{3}{8}$	37	46	56	66	35	44	53	62	33	42	50	59
$2\frac{1}{2}$	35	44	53	62	33	42	51	59	31	40	48	56
$2\frac{5}{8}$	33	42	51	60	32	40	48	57	30	38	46	54
$2\frac{3}{4}$	32	40	49	57	30	38	46	54	29	36	44	51
$2\frac{7}{8}$	31	38	47	55	29	37	44	52	27	35	42	49
3	29	37	45	52	28	35	42	50	26	33	40	47

[1] This table is based on the assumption of parting-off tool $\frac{1}{8}$ in. wide.

CALCULATION OF NUMBER OF COMPONENTS TO BE OBTAINED FROM A BAR AND BAR-END ALLOWANCE

Let:

$$L = \text{Component length (in.)}$$
$$w = \text{Parting-tool width (in.)}$$

then:

For component length less than $1\frac{1}{2}$ in.:

$$\text{Bar-end allowance} = 1\tfrac{1}{2}L + 1 \text{ in.}$$

$$\text{No. of components per bar} = \frac{N - 1{\cdot}5L}{L + w}.$$

Where " N " is obtained from the following table:

Length of Bar in ft.	8	9	10	11	12	13	14	15	16	17	18	19	20
Constant N	95	107	119	131	143	155	167	179	191	203	215	217	239

For component longer than $1\frac{1}{4}$ in.:

Bar-end allowance 3 in.

$$\text{No. of components per bar} = \frac{(\text{Length of bar in ins.}) - 3}{L + w}.$$

To allow for "x" per cent. scrap, multiply result by $\frac{100 - x}{100}$.

E.g. to allow for 5 per cent. scrap, multiply result by 0·95.

TO CONVERT FEED PER REVOLUTION TO CUTS PER INCH OF TRAVERSE

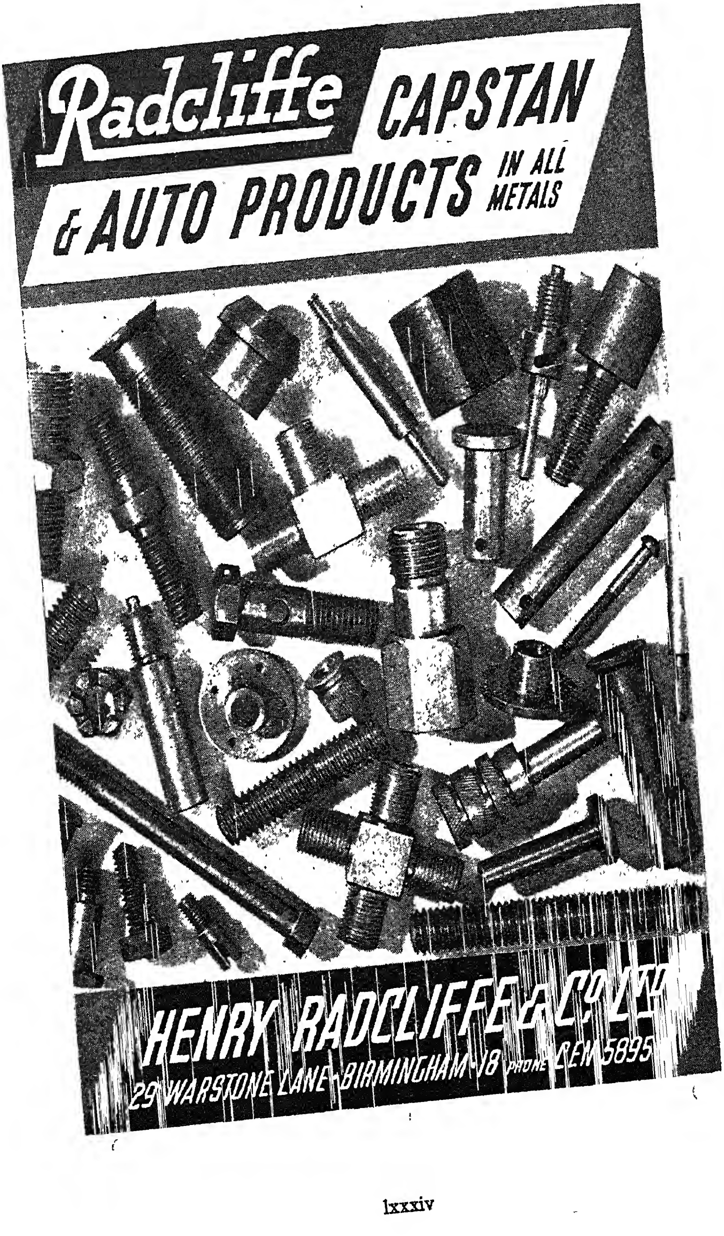
Feed per Rev. Inch	*Cuts per Inch*	*Feed per Rev. Inch*	*Cuts per Inch*	*Feed per Rev. Inch*	*Cuts per Inch*	*Feed per Rev. Inch*	*Cuts per Inch*
0·0005	2000	0·0075	133	0·0195	51·3	0·0330	30·3
0·0006	1666	0·0080	125	0·0200	50·0	0·0340	29·4
0·0007	1428	0·0085	117	0·0205	48·8	0·0350	28·6
0·0008	1250	0·0090	111	0·0210	47·6	0·0360	27·8
0·0009	1111	0·0095	105	0·0215	46·5	0·0370	27·0
0·0010	1000	0·0100	100	0·0220	45·5	0·0380	26·3
0·0012	833	0·0105	95·2	0·0225	44·4	0·0390	25·6
0·0014	714	0·0110	90·9	0·0230	43·5	0·0400	25·0
0·0016	625	0·0115	86·9	0·0235	42·5	0·0410	24·4
0·0018	555	0·0120	83·3	0·0240	41·7	0·0420	23·8
0·0020	500	0·0125	80·0	0·0245	40·8	0·0430	23·2
0·0022	454	0·0130	76·9	0·0250	40·0	0·0440	22·7
0·0024	417	0·0135	74·1	0·0255	39·2	0·0450	22·2
0·0026	385	0·0140	71·4	0·0260	38·4	0·0460	21·7
0·0028	357	0·0145	68·9	0·0265	37·7	0·0470	21·3
0·0030	333	0·0150	66·6	0·0270	37·0	0·0480	20·8
0·0035	286	0·0155	64·5	0·0275	36·4	0·0490	20·4
0·0040	250	0·0160	62·5	0·0280	35·7	0·0500	20·0
0·0045	222	0·0165	60·6	0·0285	35·1	0·0550	18·2
0·0050	200	0·0170	58·8	0·0290	34·4	0·0600	16·7
0·0055	182	0·0175	57·1	0·0295	33·9	0·0700	14·3
0·0060	167	0·0180	55·5	0·0300	33·3	0·0700	12·5
0·0065	154	0·0185	54·1	0·0310	32·2	0·0900	11·1
0·0070	143	0·0190	52·6	0·0320	31·2	0·1000	10·0

ATTACHMENTS

As an addition to the normal capstan lathe several attachments may be fitted. These attachments include bar feed attachment, which can be either weight driven or hand driven. This attachment feeds the bar forward when the collet chuck is released.

Chasing Attachment.—This attachment fits to the saddle of the machine, and consists of a half-nut or split nut which engages with a leader screw, which in some cases is of the same pitch as the thread to be cut and is replaceable for different pitches of thread, or alternatively can be driven through pick-off gears in the same manner as the lead screw of a centre lathe.

Taper Turning Attachment.—This attachment also fits to the saddle, and is usually carried at the back of the machine. It usually consists of an adjustable slide fitted to the bed casting which engages with a sliding block fixed to the rear of the cross slide. Thus with longitudinal traverse given to the saddle, the cross slide is so controlled that the component is turned to a taper.



Radcliffe CAPSTAN
& AUTO PRODUCTS IN ALL METALS
HENRY RADCLIFFE & Co. Ltd.
29 WARSTONE LANE BIRMINGHAM 18 PHONE CEN 5895

TIME IN SECONDS TO TRAVERSE ONE INCH

Rev. per Min.	Feed per Revolution. In Inches										
	0·0005	0·001	0·002	0·003	0·004	0·005	0·010	0·020	0·040	0·080	0·100
20	6000	3000	1500	1000	750	600	300	150	75·0	37·5	30·0
40	3000	1500	750	500	375	300	150	75·0	37·5	18·8	15·0
60	2000	1000	500	333	250	200	100	50·0	25·0	12·5	10·0
80	1500	750	375	250	188	150	75·0	37·5	18·8	9·4	7·5
100	1200	600	300	200	150	120	60·0	30·0	15·0	7·5	6·0
120	1000	500	250	167	125	100	50·0	25·0	12·5	6·3	5·0
140	857	429	214	146	107	85·7	42·9	21·4	10·7	5·4	4·29
160	750	375	188	125	93·7	75·0	37·5	18·8	9·4	4·7	3·75
180	666	333	167	111	83·3	66·7	33·3	16·7	8·3	4·6	3·33
200	600	300	150	100	75·0	60·0	30·0	15·0	7·5	3·8	3·00
225	532	266	133	88·7	66·7	53·2	26·6	13·3	6·7	3·3	2·66
250	480	240	120	80·0	60·0	48·0	24·0	12·0	6·0	3·0	2·40
275	436	218	109	72·7	54·5	43·6	21·8	10·9	5·5	2·8	2·18
300	400	200	100	66·7	50·0	40·0	20·0	10·0	5·0	2·5	2·00
350	342	171	85·5	57·0	42·7	34·2	17·1	8·6	4·3	2·1	1·71
400	300	150	75·0	50·0	37·5	30·0	15·0	7·5	3·8	1·9	1·50
450	266	133	66·5	44·4	33·3	16·7	13·3	6·7	3·3	1·6	1·33
500	250	125	62·5	41·6	31·3	24·0	12·5	6·3	3·1	1·56	1·25
550	218	109	54·5	36·3	27·3	21·8	10·9	5·5	2·7	1·36	1·09
600	200	100	50·0	33·3	25·0	20·0	10·0	5·0	2·5	1·25	1·00
650	185	92·3	46·1	30·8	23·1	18·5	9·2	4·6	2·3	1·15	0·92
700	171	85·7	42·7	28·5	21·4	17·1	8·6	4·3	2·1	1·07	0·86
750	160	80·0	40·0	26·7	20·0	16·0	8·0	4·0	2·0	1·00	0·80
800	150	75·0	37·5	25·0	18·7	15·0	7·5	3·8	1·9	0·93	0·75
850	141	70·6	35·3	23·5	17·6	14·1	7·1	3·5	1·8	0·88	0·71
900	133	66·7	33·3	22·2	16·7	13·3	6·7	3·3	1·7	0·83	0·67
950	126	63·1	31·6	21·0	15·8	12·6	6·3	3·2	1·6	0·79	0·63
1000	120	60·0	30·0	20·0	15·0	12·0	6·0	3·0	1·5	0·75	0·60

Form Tools.—The main types are : simple (solid and dovetail types), circular, and above-centre type.

Simple. Allowance for top rake. In Fig. 10, let :

A = Minor radius of step.
B = Major radius of step.
C = Step of tool.
$t°$ = Top rake of tool.

then $C = \cos t° \left\{ \sqrt{B^2 - x} - \sqrt{A^2 - x} \right\}$

where $x = A^2 \sin^2 t°$.

Allowance for Front Clearance.—In Fig. 11, let :

D = Step on work-piece.
E = Dimension at right angles to front clearance. (Dimension required for grinding.)
c = Clearance angle.

then $E = D \cos c$.

Combined Allowance for Top Rake and Clearance.—In Fig. 12,

$$E = C \cos c.$$
$$= \cos t \cos c\left\{\sqrt{B^2 - x} - \sqrt{A^2 - x}\right\}.$$

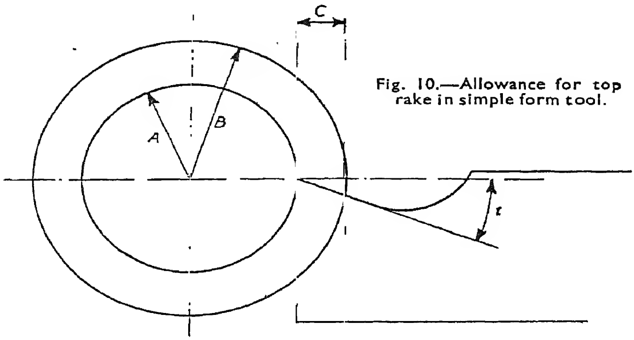


Fig. 10.—Allowance for top rake in simple form tool.

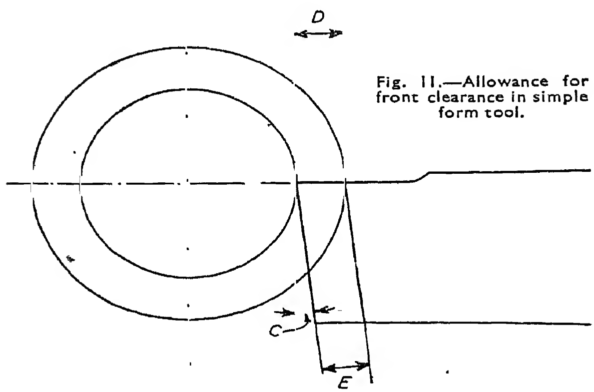


Fig. 11.—Allowance for front clearance in simple form tool.

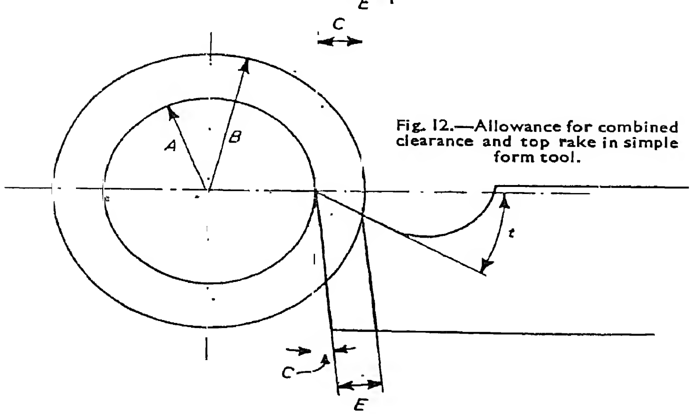


Fig. 12.—Allowance for combined clearance and top rake in simple form tool.

Circular.—Connection between above-centre height and clearance angle is shown in Fig. 13. Let :

R = Radius of tool.
h = Above-centre height.
a = Clearance angle.
then h = R tan a.

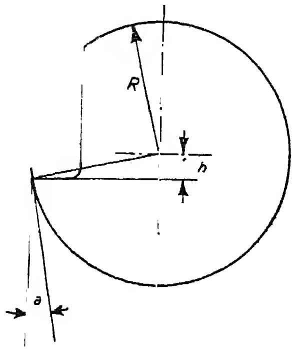


Fig. 13.—Showing connection between clearance angle and centre height.

Calculation of Tool Dimensions.—For a tool without top rake (Fig. 14) let :

A = Minor radius of work-piece.
B = Major radius of work-piece.
C = Radial step.
R = Major radius of circular form tool.
r = Minor radius of circular form tool.
h = Above-centre height of circular form tool.

then C = B − A.

With given diameter 2R :

$$r = \sqrt{(\sqrt{R^2 - h^2} - C)^2 + h^2}.$$

With given diameter $2r$:

$$R = \sqrt{(\sqrt{r^2 - h^2} + C)^2 + h^2}.$$

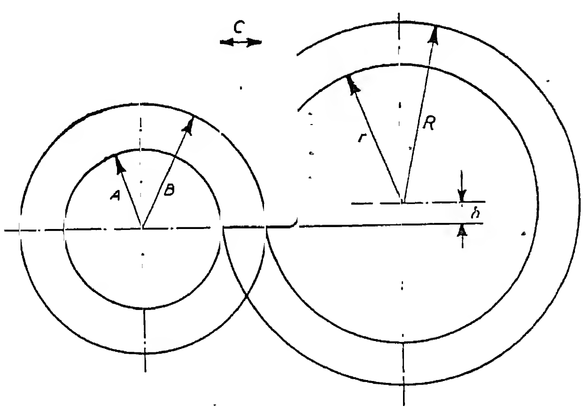


Fig. 14.—Circular form tool without top rake.

Calculation Involving Top Rake.—In addition to previous symbols (see Fig. 15) let:

t° = Top-rake angle.
s = Slant face of form tool.
a = Clearance angle.

then in $\triangle$ XYO

$$r^2 = R^2 + s^2 - 2sR\cos\theta.$$

$$r = \sqrt{R^2 + s^2 - 2sR\cos\theta}.$$

Investigating "s":

$$s = \frac{v}{\sin t}$$

$$\text{but } \beta = (t - \phi).$$
$$\text{and } v = B\sin\beta.$$
$$\therefore v = B\sin(t - \phi).$$

$$\text{Since } \sin\phi = \frac{A\sin t}{B}$$

$$\therefore v = B\sin\left(t - \sin^{-1}\frac{A\sin t}{B}\right).$$

$$s = \frac{B\sin\left(t - \sin^{-1}\frac{A\sin t}{B}\right)}{\sin t}.$$

Hence the procedure is:

(1) Obtain "s" from

$$s = \frac{B\sin\left(t - \sin^{-1}\frac{A\sin t}{B}\right)}{\sin t}.$$

(2) Obtain θ from

$$\theta = t + a.$$
$$a = \sin^{-1}\frac{h}{R}.$$

Substitute s and θ in main formula:

$$r = \sqrt{R^2 + s^2 - 2sR\cos\theta}.$$

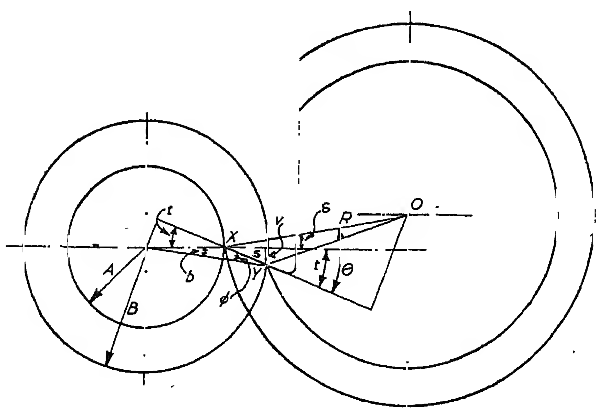


Fig. 15.—Circular form tool with top rake.

Above-centre Form Tools.—The above-centre type form tool is a form tool which has been developed for use on very free-cutting materials, such as aluminium alloys, etc. Its main sphere of usefulness is in work of a simple nature without a great deal of " step."

The main attractions of this tool are the ease with which it can be resharpened by unskilled labour by placing the tool upon the magnetic face-plate of the surface grinder and taking a skim over the top face of the tool, and also the advantageous use of tungsten-carbide tips, whereby the shank is not weakened by a cut-away to receive the tip. Furthermore a large top-rake angle can very easily be accommodated without wastage to the tip.

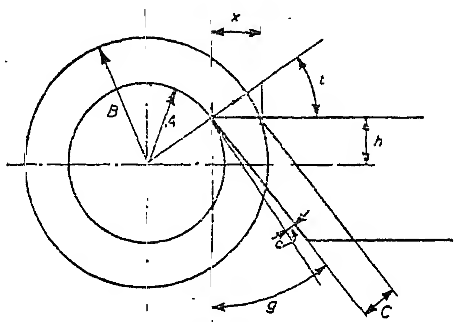


Fig. 16.—Above-centre type of form tool.

The calculation of above-centre height and clearance angle for given top rake is now given (see Fig. 16). Let:

t = Top-rake angle required.
c = Clearance angle required.
g = Grinding angle.
h = Above-centre setting.
A = Minor radius of work-piece.
B = Major radius of work-piece.
C = Grinding dimension of tool.

then $h = a \cos t$

and $g = c + t$,

also $\mathrm{C} = \cos t\{\sqrt{\mathrm{B}^2 - \mathrm{A}^2 \sin^2 t} - \mathrm{A} \cos t\}$

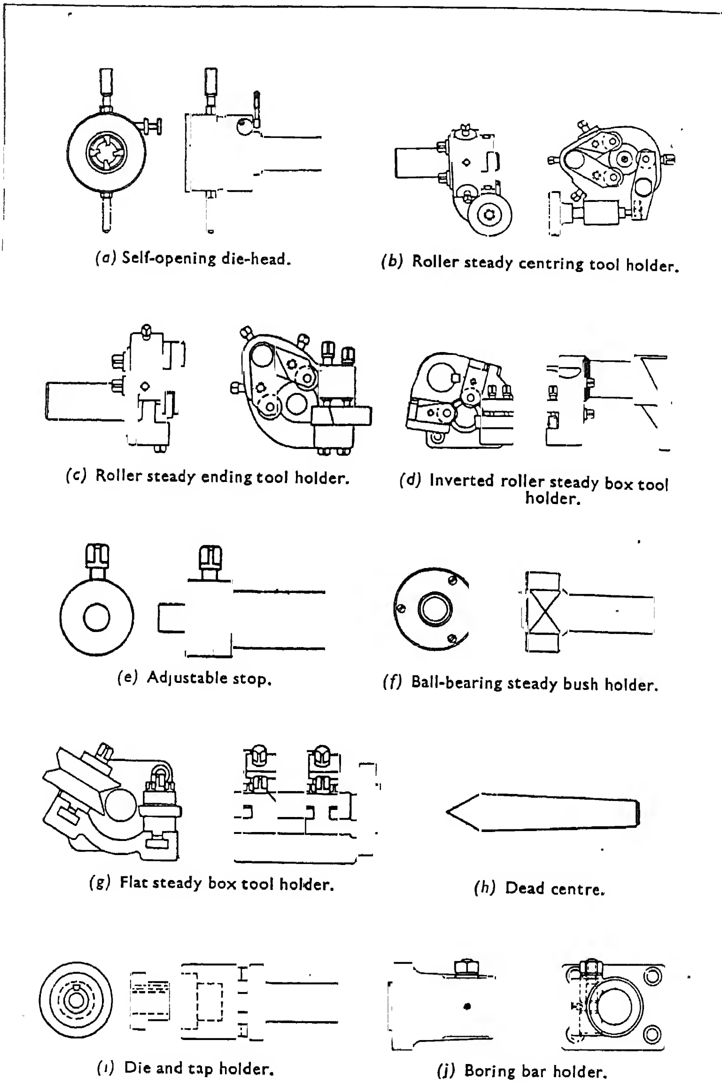
or $\mathrm{C} = \cos t\{\sqrt{\mathrm{B}^2 - h^2} - a \cos t\}$.

Special Tools Used.—Several special tools are used with the capstan or turret lathe, some of the more usual of which are illustrated in Figs. 17 to 20.

Fig. *a* shows the self-opening die-head, which consists of a set of chasers held in a body so constructed that at the completion of the forward movement of the turret ram the chasers are withdrawn so that the die-head can be brought back over the work-piece without any interference with the thread which has just been cut.

Fig. *b* is the roller steady centring tool holder. This tool is used to centre the ends of bars, the rollers being adjusted to bear upon the periphery of the bar.

Fig. *c* shows a roller steady ending tool holder. This is used for facing ends of components. This tool is useful to carry a form tool " to face end and chamfer " or " round end."



(a) Self-opening die-head.

(b) Roller steady centring tool holder.

(c) Roller steady ending tool holder.

(d) Inverted roller steady box tool holder.

(e) Adjustable stop.

(f) Ball-bearing steady bush holder.

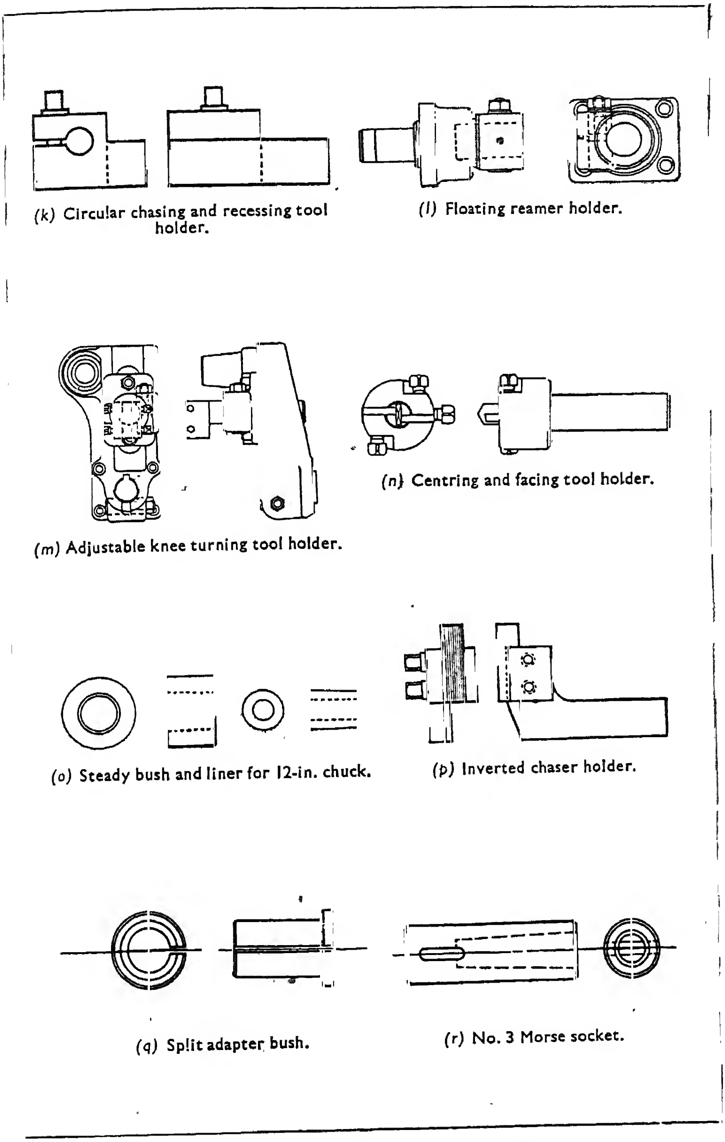
(g) Flat steady box tool holder.

(h) Dead centre.

(i) Die and tap holder.

(j) Boring bar holder.

Fig. 17.—Capstan tools for bar and chuck work.



(*k*) Circular chasing and recessing tool holder.

(*l*) Floating reamer holder.

(*m*) Adjustable knee turning tool holder.

(*n*) Centring and facing tool holder.

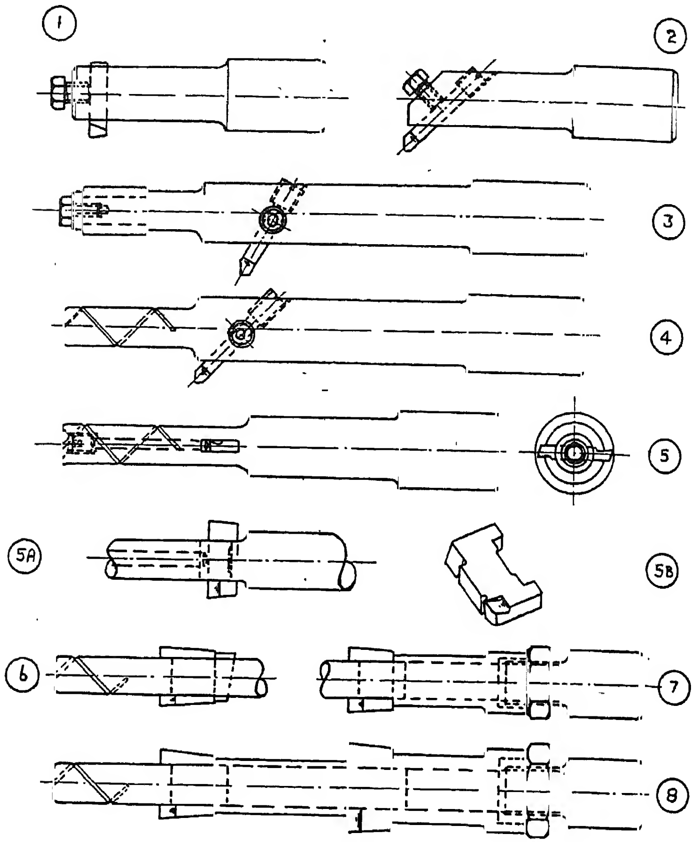
(*o*) Steady bush and liner for 12-in. chuck.

(*p*) Inverted chaser holder.

(*q*) Split adapter bush.

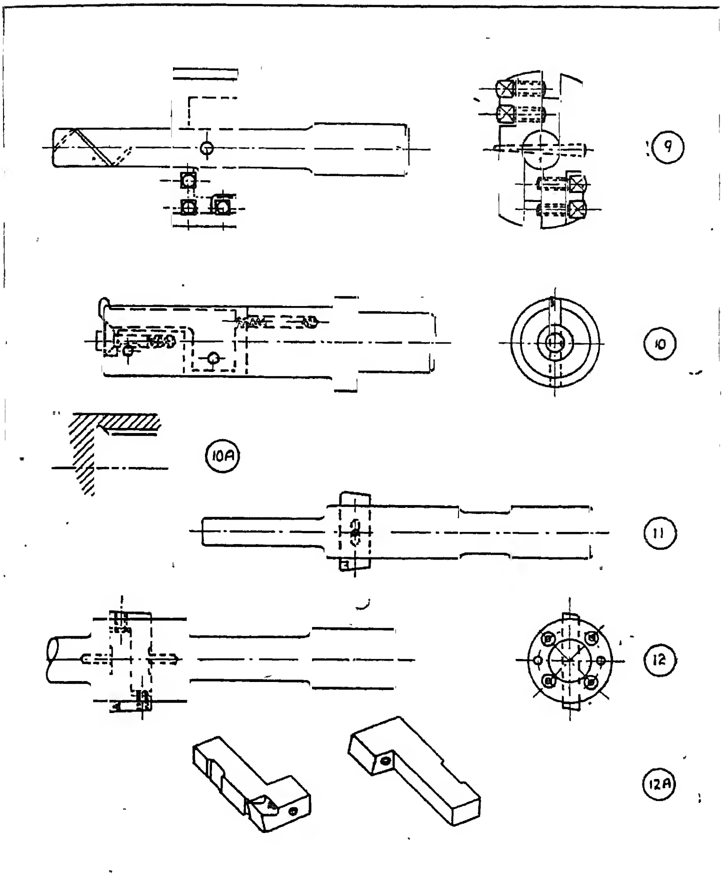
(*r*) No. 3 Morse socket.

Fig. 18.—Further capstan tools for bar and chuck work.



1. Stub bar.
2. Stub bar with angular tool bit.
3. Piloted boring bar, with hardened-steel sleeve which rotates to prevent seizing at high speeds.
4. Piloted bar without sleeve.
5. Bar with blade cutter insert.
5A. Plan view of cutter insert.
5B. Detail of cutter insert.
6. Cutter blade fixed by wedge.
7. Cutter blade held by nut and sleeve.
8. Method of holding several blades in one bar.

Fig. 19.—Some useful boring bars.



9. Boring bar suitable for large diameters.
10. Boring bar which automatically produces an undercut at the end of a blind hole.
10A. Type of undercut produced.
11. Boring bar with floating cutter blade.
12. Boring bar with floating cutter blade adjustable on diameter.
12A. Details of floating adjustable cutter blade.

Fig. 20.—Some further types of boring bars.

Fig. *d* is an inverted roller steady box tool holder. Used for turning to shoulder. For instance, turning the shank of bolts.

Fig. *e* is the adjustable stop. Used to control the length of bar advanced to make a component. Usually, though not always, the first operation.

Fig. *f* is the ball-bearing steady bush holder. Used to support the outer end of a component whilst a heavy forming cut is being taken.

Fig. *g* is the flat steady box tool holder. Used similarly to Fig. *d*, but can accommodate several diameters at one setting for turning stepped shafts, etc.

Fig. *h* is the dead centre. Used for supporting long shafts during turning, tubular work, etc.

Fig. *i* is the die and tap holder. Die and tap holders used on the turret lathe are arranged so that the die or tap is carried in a holder which is prevented from turning by dogs fitted to the shank. These dogs are so arranged that upon the turret ram reaching the stop at the end of the stroke, the forward pull of the component, being threaded, withdraws the die holder from the dogs, which allows the die or tap to rotate with the work and so controls the length of thread obtained.

Fig. *j* is a boring bar holder.

Fig. *k* is a circular chasing and recessing tool holder. Used on the cross slide.

Fig. *l* shows a floating reamer holder. Used in the turret for reaming under power. The float is to allow the reamer to find its own centre and so ensures an accurate hole.

Fig. *m* is an adjustable knee-turning tool holder. This tool is used for turning fairly large diameters. It is provided with a steady bush which slides along the steady bar carried in the headstock. This imparts extra rigidity to the turning tool and ensures accurate results. Some designs of knee-turning tool holders allow more than one turning tool to be carried and so permit several diameters to be turned at one setting.

Fig. *n* is a centring and facing tool holder. This tool combines the operation of Figs. *b* and *c*, but is unsuitable on long components owing to "whip" and so for such components use should be made of tools, Figs. *b* and *c*, and the centring and facing tool holder should be used on short, stubby components.

Fig. *o* is a steady bush and liner for chuck. Such bushes are used to support the end of the boring bar, which is fitted with a pilot for such purpose. This allows heavier cuts to be taken when boring and also ensures accuracy of the hole produced.

Fig. *p* is an inverted chaser holder. Used on the cross slide.

Fig. *q* is a split adapter bush. Used with tool, Fig. *j*, to take different-size boring bars; also with tool, Fig. *l*, to accommodate reamers with different-size shanks.

Fig. *r* is a morse socket. Used to carry tools such as drills, etc., with tapered shanks in the plain-bored holes of the turret head.

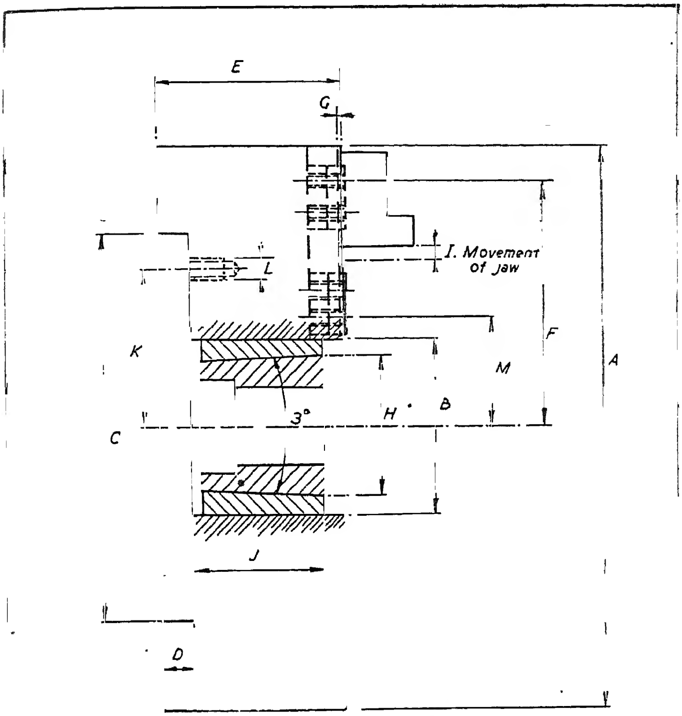
CHUCKS

The expense of special fixtures for gripping castings, forgings, etc., can often be mitigated by modifying a set of soft jaws to be used with a special type of chuck. The jaws can be so shaped that they locate and grip the forging. Frequently such jaws can be made from standard blanks already machined to fit the particular chuck in question. A stock of such blanks suited to the chucks possessed by the manufacturer will frequently save delay when dealing with a new component.

A selection of dimensioned drawings for jaws suitable to a few popular chucks expressly designed for use with such jaws is given in the following pages.

Air Chucks.—Chucks for use with soft jaws which are opened and closed by air pressure have the further advantage of high gripping power without great physical strain to the operator.

Where the use of special jaws is not possible, as is sometimes the case with particularly difficult components, the air-operated push bar which actuates the chuck can frequently be made to actuate the special fixture necessary.

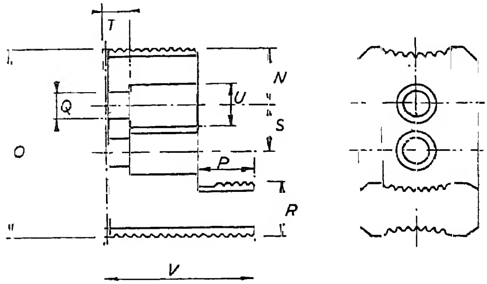


On the 28-in. chuck only, the six holes "L" are clearance holes passing right through the chuck, and are spaced alternately 50° and 70° apart.

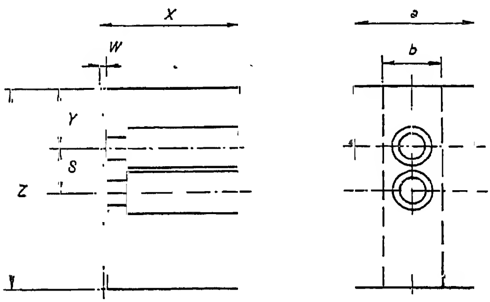
CHUCK BODY

Size of Chuck	A	B	C	D	E	F	G	H	I	J	K	L	M
6″	6	$1\frac{5}{16}$	$5\frac{1}{4}$	$\frac{3}{16}$	$2\frac{5}{16}$	$2\frac{9}{16}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{3}{16}$	$1\frac{7}{8}$	$2\frac{11}{32}$	3, $\frac{3}{8}$″	$\frac{29}{32}$
$7\frac{1}{2}$″	$7\frac{1}{2}$	$1\frac{5}{16}$	$5\frac{1}{4}$	$\frac{3}{16}$	$2\frac{21}{64}$	$3\frac{1}{8}$	$\frac{1}{16}$	$\frac{15}{16}$	$\frac{3}{16}$	$1\frac{7}{8}$	$2\frac{11}{32}$	3, $\frac{3}{8}$″	$1\frac{1}{4}$
9″	$9\frac{1}{2}$	$2\frac{9}{16}$	$7\frac{1}{2}$	$\frac{5}{16}$	$3\frac{5}{16}$	$4\frac{1}{16}$	$\frac{1}{16}$	$2\frac{3}{16}$	$\frac{5}{32}$	$2\frac{3}{4}$	3[illegible]	3, $\frac{1}{2}$″	$1\frac{9}{16}$
12″	$12\frac{1}{2}$	$3\frac{3}{4}$	$7\frac{1}{2}$	$\frac{1}{2}$	$3\frac{7}{16}$	$5\frac{5}{8}$	$\frac{1}{16}$	$3\frac{1}{16}$	$\frac{3}{16}$	$2\frac{11}{16}$	3[illegible]	3, [illegible]″	$2\frac{1}{4}$
15″	$15\frac{1}{2}$	$4\frac{3}{4}$	10	$\frac{5}{8}$	$4\frac{1}{8}$	$6\frac{3}{4}$	$\frac{3}{32}$	$3\frac{3}{4}$	[illegible]	$3\frac{1}{4}$	4	4, [illegible]″	$2\frac{13}{16}$
18″	$18\frac{3}{4}$	$5\frac{1}{2}$	10	$\frac{13}{16}$	$4\frac{9}{16}$	$8\frac{1}{8}$	$\frac{3}{32}$	$4\frac{1}{2}$	[illegible]	$3\frac{1}{2}$	4	4, [illegible]″	$3\frac{3}{8}$
21″	$21\frac{3}{4}$	$6\frac{1}{4}$	$14\frac{1}{4}$	$\frac{7}{8}$	$5\frac{1}{4}$	$9\frac{1}{2}$	$\frac{3}{32}$	5	[illegible]	4	$6\frac{1}{16}$	6, $\frac{7}{8}$″	$3\frac{13}{16}$
25″	25	$7\frac{5}{16}$	14[illegible]	$\frac{7}{8}$	5[illegible]	$10\frac{3}{4}$	$\frac{3}{32}$	$5\frac{3}{4}$	[illegible]	$3\frac{9}{16}$	$6\frac{1}{16}$	6, $\frac{7}{8}$″	$4\frac{3}{16}$
28″	28	$8\frac{9}{16}$	15[illegible]	$\frac{7}{8}$	5[illegible]	$11\frac{5}{8}$	$\frac{3}{32}$	$7\frac{1}{4}$	$\frac{1}{4}$	4	$6\frac{5}{8}$	6, $\frac{15}{16}$″	$5\frac{3}{16}$
32″	32	$8\frac{3}{4}$	16	$1\frac{11}{16}$	$7\frac{5}{16}$	$13\frac{1}{8}$	$\frac{3}{32}$	$7\frac{1}{4}$	$\frac{5}{16}$	5	$6\frac{7}{8}$	6, 1″	$5\frac{1}{8}$

Fig. 21.—Herbert Coventry chuck.



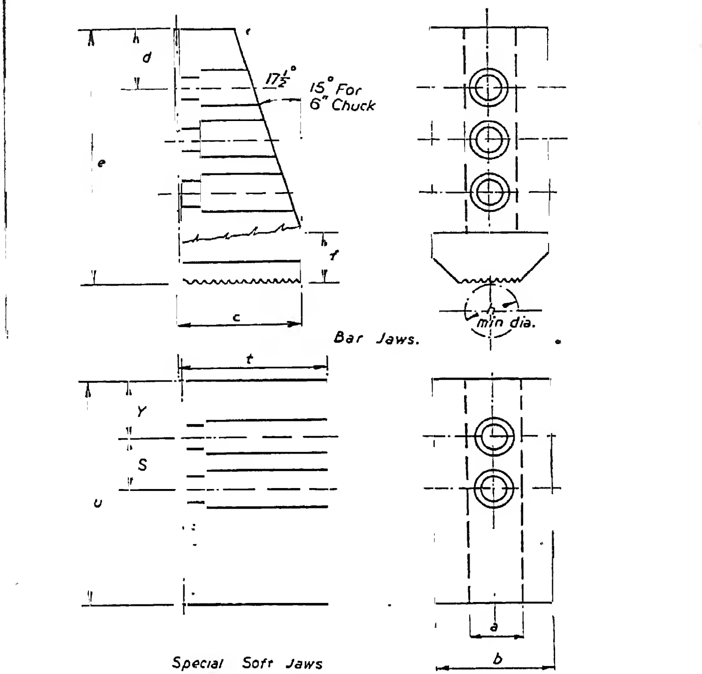
Hard Jaws



Soft Jaws

HARD JAWS									SOFT JAWS					
N	*O*	*P*	*Q*	*R*	*S*	*T*	*U*	*V*	*W*	*X*	*Y*	*Z*	*a*	*b*
$\frac{15}{32}$	$1\frac{7}{8}$	$\frac{3}{8}$	$\frac{21}{64}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{23}{64}$	$\frac{9}{16}$	$1\frac{7}{64}$	$\frac{1}{8}$	$1\frac{15}{64}$	$\frac{5}{8}$	$2\frac{1}{8}$	1	0·502 0·500
$\frac{15}{32}$	$1\frac{7}{8}$	$\frac{3}{8}$	$\frac{21}{64}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{23}{64}$	$\frac{9}{16}$	$1\frac{7}{64}$	$\frac{1}{8}$	$1\frac{15}{64}$	$\frac{5}{8}$	$2\frac{1}{8}$	1	0·502 0·500
$\frac{11}{16}$	$2\frac{13}{32}$	$\frac{1}{2}$	$\frac{15}{32}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{9}{16}$	$\frac{11}{16}$	$1\frac{9}{16}$	$\frac{5}{32}$	$1\frac{3}{4}$	$\frac{13}{16}$	$2\frac{3}{4}$	$1\frac{5}{16}$	0·627 0·625
$\frac{23}{32}$	$3\frac{1}{32}$	$\frac{3}{4}$	$\frac{17}{32}$	$\frac{3}{4}$	$\frac{29}{32}$	$\frac{17}{32}$	$\frac{3}{4}$	$1\frac{7}{8}$	$\frac{5}{32}$	2	$\frac{3}{4}$	3	$1\frac{1}{2}$	0·689 0·687
$\frac{29}{32}$	$3\frac{11}{16}$	$\frac{13}{16}$	$\frac{21}{32}$	$\frac{13}{16}$	$1\frac{3}{16}$	$\frac{11}{16}$	1	$2\frac{3}{16}$	$\frac{5}{32}$	$2\frac{1}{4}$	1	$3\frac{3}{4}$	$1\frac{3}{4}$	0·815 0·812
$1\frac{5}{64}$	$4\frac{1}{4}$	$\frac{7}{8}$	$\frac{25}{32}$	1	$1\frac{3}{8}$	$\frac{3}{4}$	$1\frac{3}{16}$	$2\frac{7}{16}$	$\frac{3}{16}$	$2\frac{1}{2}$	$1\frac{1}{16}$	$4\frac{1}{4}$	$2\frac{1}{8}$	1·003 1·001
$1\frac{9}{16}$	$5\frac{3}{8}$	1	$\frac{25}{32}$	$1\frac{3}{16}$	$1\frac{5}{8}$	$\frac{27}{32}$	$1\frac{3}{16}$	$2\frac{11}{16}$	$\frac{1}{4}$	3	$1\frac{11}{16}$	$5\frac{3}{8}$	$2\frac{1}{4}$	1·003 1·001
$1\frac{19}{32}$	$6\frac{9}{32}$	$1\frac{1}{8}$	$\frac{25}{32}$	$1\frac{13}{32}$	$2\frac{1}{8}$	$\frac{27}{32}$	$1\frac{3}{16}$	$2\frac{15}{16}$	$\frac{1}{4}$	$3\frac{1}{4}$	$1\frac{5}{8}$	$6\frac{1}{4}$	$2\frac{1}{4}$	1·003 1·001
$1\frac{7}{8}$	$6\frac{11}{16}$	$1\frac{1}{8}$	$\frac{25}{32}$	$1\frac{13}{32}$	$2\frac{3}{8}$	$\frac{27}{32}$	$1\frac{3}{16}$	$2\frac{15}{16}$	$\frac{1}{4}$	$3\frac{1}{4}$	$1\frac{5}{8}$	$6\frac{3}{4}$	$2\frac{1}{4}$	1·003 1·001
$1\frac{27}{32}$	$7\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{1}{32}$	$1\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{11}{16}$	$3\frac{5}{8}$	$\frac{3}{8}$	4	$1\frac{7}{8}$	$7\frac{3}{4}$	$2\frac{7}{8}$	1·253 1·251

Fig. 22.—Jaws for Herbert Coventry chuck.



Bar Jaws						Special Soft Jaws	
c	*d*	*e*	*f*	*h*		*t*	*u*
$1\frac{1}{8}$	$\frac{11}{16}$	$2\frac{5}{16}$	$\frac{7}{8}$	$\frac{5}{16}$		2	3
$1\frac{1}{8}$	$\frac{11}{16}$	$2\frac{5}{16}$	$\frac{7}{8}$	$\frac{13}{16}$		2	3
$1\frac{9}{16}$	$1\frac{1}{8}$	$3\frac{19}{64}$	$\frac{1}{2}$	$\frac{3}{8}$		$2\frac{3}{4}$	$3\frac{1}{4}$
$1\frac{13}{16}$	$1\frac{7}{32}$	$4\frac{9}{32}$	$\frac{7}{16}$	$\frac{1}{2}$		3	4
$2\frac{7}{32}$	$1\frac{11}{32}$	$5\frac{19}{64}$	$\frac{1}{2}$	$\frac{5}{8}$		$3\frac{1}{4}$	$4\frac{3}{4}$
$2\frac{19}{32}$	$1\frac{47}{64}$	$6\frac{5}{16}$	$\frac{9}{16}$	$\frac{3}{4}$		$3\frac{1}{2}$	$5\frac{1}{2}$
$3\frac{7}{64}$	$2\frac{1}{4}$	$7\frac{11}{32}$	$\frac{9}{16}$	$\frac{7}{8}$		$4\frac{1}{4}$	$6\frac{3}{4}$
3[illegible]	$2\frac{5}{32}$	$7\frac{59}{64}$	$\frac{15}{16}$	$1\frac{1}{4}$		$4\frac{3}{4}$	$7\frac{1}{2}$
$3\frac{5}{8}$	$2\frac{5}{32}$	$8\frac{11}{16}$	$1\frac{7}{8}$	2		—	—
$4\frac{1}{2}$	2	$9\frac{1}{4}$	$1\frac{1}{8}$	$3\frac{3}{16}$		—	—

Fig. 23.—Jaws for Herbert Coventry chuck.

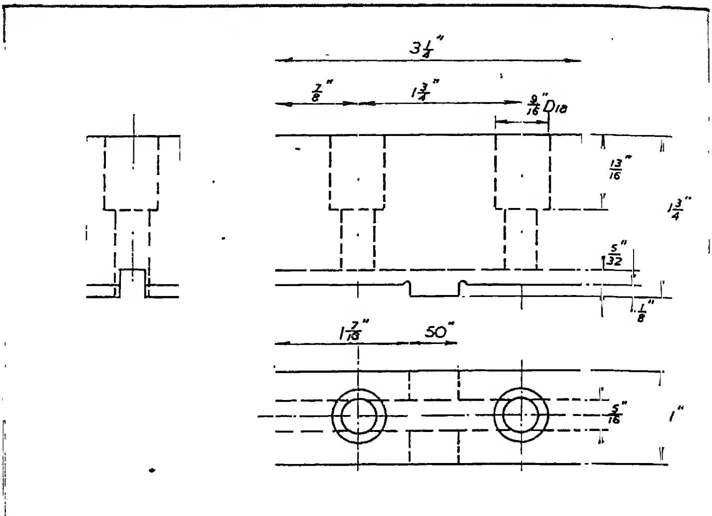


Fig. 24.—Soft jaw blanks for Union 3-jaw chuck (with replaceable jaws). 8 in.

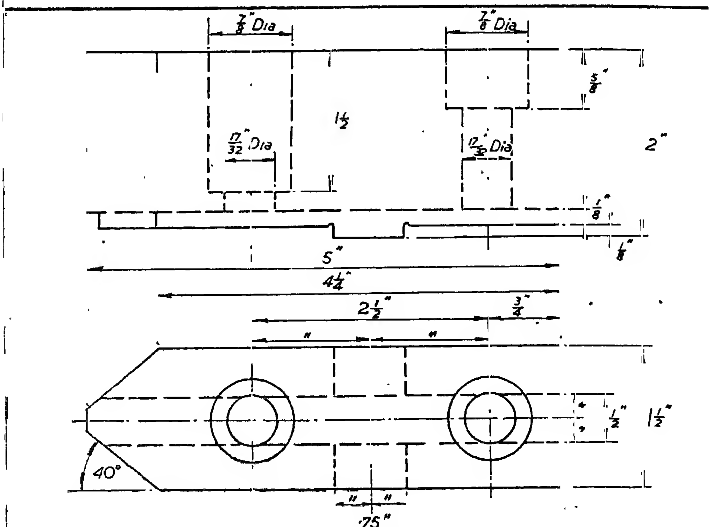


Fig. 25.—Soft jaw blanks for Union 3-jaw chuck (with replaceable jaws). 12 in.

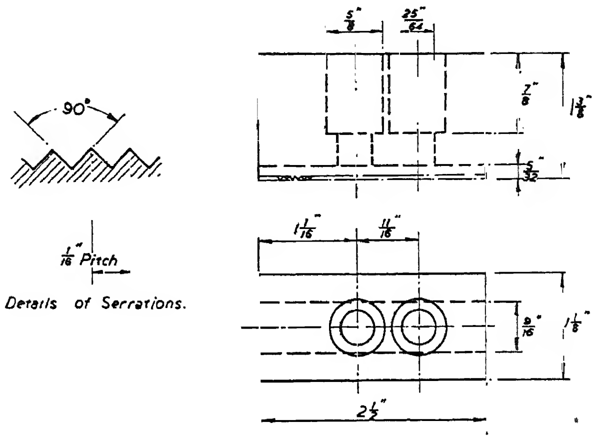


Fig. 26.—Soft jaw blanks for Tudor 3-jaw chuck (with replaceable jaws). 9 in.

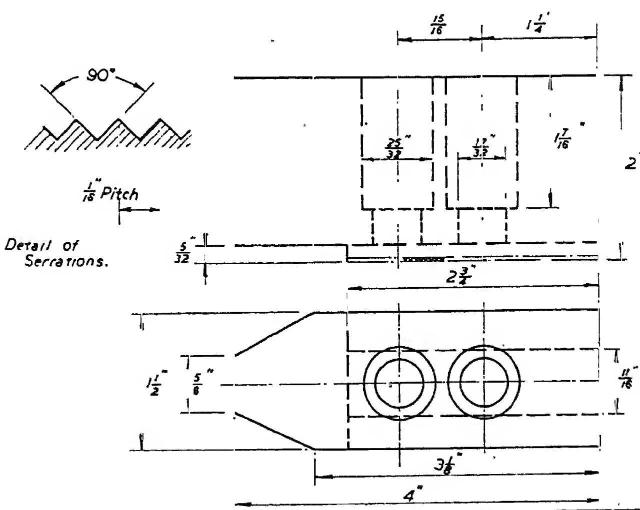


Fig. 27.—Soft jaw blanks for Tudor 3-jaw chuck (with replaceable jaws). 12 in.

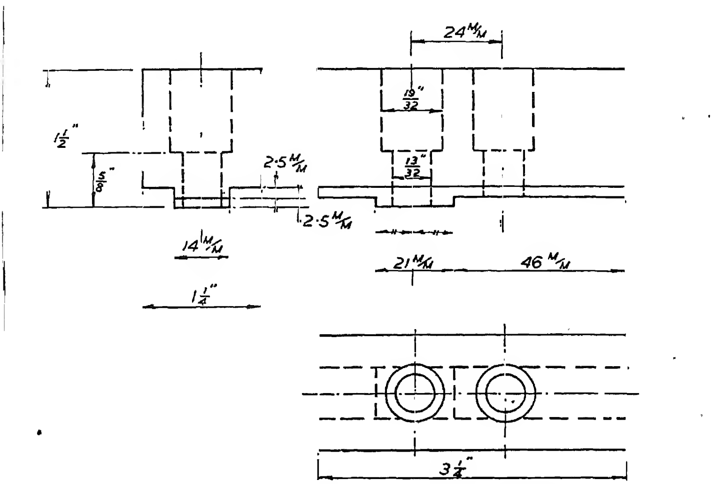


Fig. 28.—Soft jaw blanks for Harles 3-jaw chuck (with replaceable jaws). 7½ in.

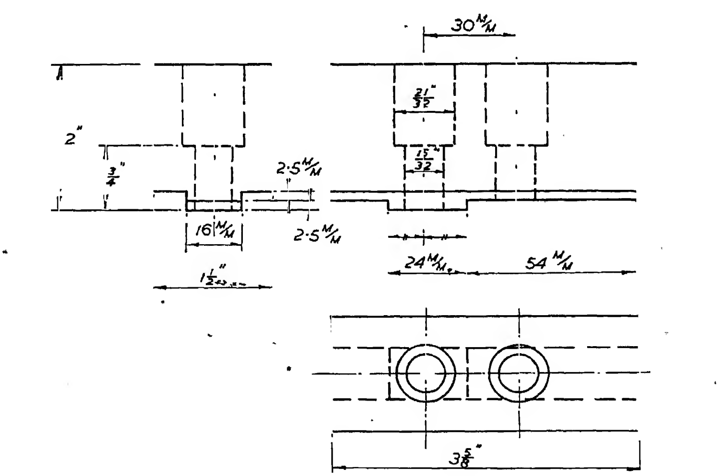


Fig. 29.—Soft jaw blanks for Harles 3-jaw chuck (with replaceable jaws). 9 in.

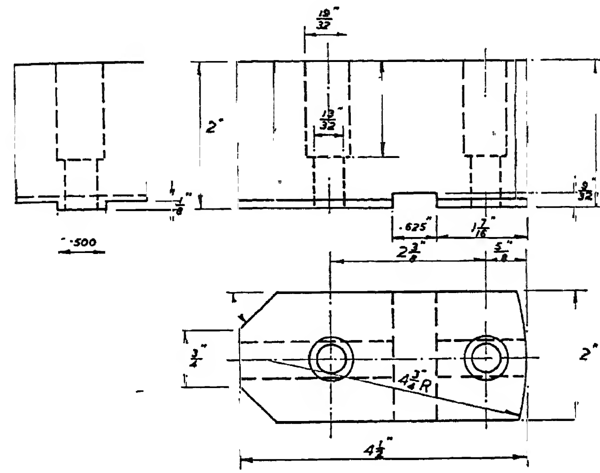


Fig. 30.—Soft jaws for Pratt 2-jaw chuck (with replaceable jaws). 9 in.

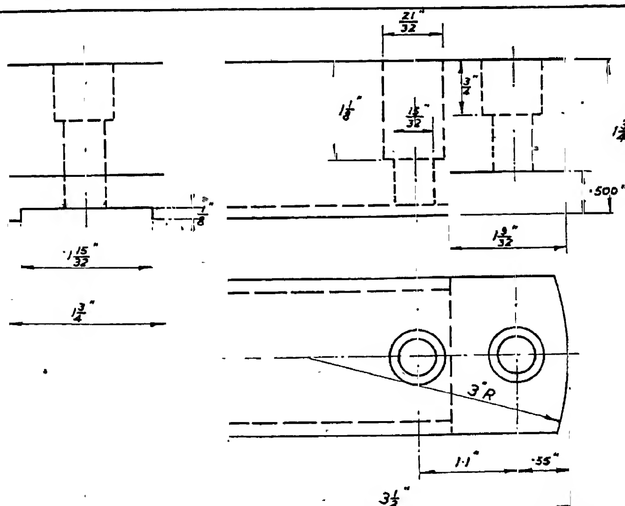


Fig. 31.—Soft jaws for Taylor 2-jaw chuck (with replaceable jaws). 6½ in.

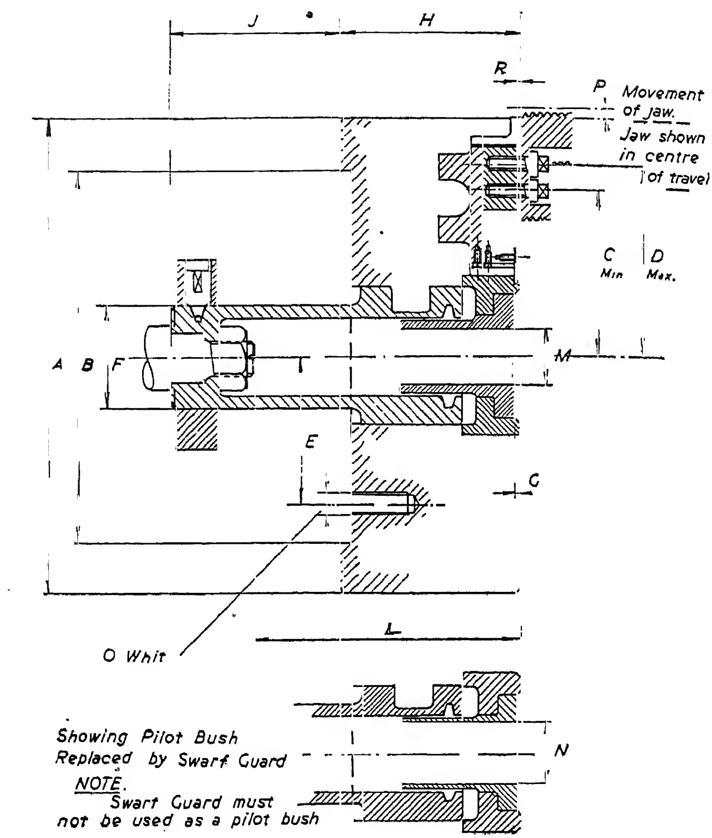


Fig. 32.—The Herbert 9-in. to 32-in. air chuck.

As will be seen from the table on p. 525, the type of chuck shown above is supplied in 9 in. (two- or three-jaw), 12 in. (three-jaw), 15 in. (three-jaw), 18 in. (three-jaw), 21 in. (three-jaw), 25 in. (three-jaw), 32 in. (three-jaw). They are suitable for use on Herbert capstan lathes, auto lathes, and combination turret lathes; also any other make of machine having a hollow spindle.

The chuck jaws are adjusted in the same way as those on the Coventry chucks. The air pressure required is 80 lb. per sq. in. The type L two-jaw air chucks are, of course, intended for work requiring a fairly light grip and are especially useful in the brass trade. The jaw stroke is the same as the piston movement in the air cylinder. The type LA is similar to the type L with the exception of the jaw carriers and jaws. The jaws are adjustable and the inner faces are dovetailed to suit requirements for the fitting of loose pads to suit different sizes and shapes of work.

HERBERT AIR CHUCK—9-IN. TO 32-IN.

Size of Chuck	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*L*	*K*	
	in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	
9 in. (2 or 3 Jaw)	$9\frac{1}{2}$	7·500 7·4985	$1\frac{31}{32}$	$3\frac{31}{32}$	$3\frac{1}{8}$	2	$\frac{3}{32}$	$3\frac{11}{16}$	$3\frac{3}{4}$ max. 3 min.	$\frac{5}{16}$	
12 in. (3 Jaw)	$12\frac{1}{2}$	7·500 7·4985	$2\frac{11}{16}$	$5\frac{3}{32}$	$3\frac{1}{8}$	2	$\frac{3}{32}$	$3\frac{7}{8}$	$3\frac{3}{4}$ max. 3 min.	$\frac{5}{16}$	
15 in. (3 Jaw)	$15\frac{1}{2}$	10·000 9·9985	3	$6\frac{9}{16}$	4	$3\frac{1}{2}$	$\frac{1}{8}$	$5\frac{1}{4}$	$8\frac{5}{16}$ max. $6\frac{13}{16}$ min.	$\frac{5}{8}$	
18 in. (3 Jaw)	$8\frac{3}{4}$	10·000 9·9985	$3\frac{11}{16}$	$7\frac{7}{8}$	4	$3\frac{5}{16}$	$\frac{5}{32}$	$5\frac{3}{16}$	$8\frac{13}{16}$ max. $7\frac{5}{16}$ min.	$\frac{13}{16}$	
21 in. (3 Jaw)	$21\frac{3}{4}$	14·250 14·2485	$4\frac{3}{8}$	$9\frac{7}{32}$	$6\frac{1}{16}$	$4\frac{1}{8}$	Pilot Bush is flush with face of Chuck	$6\frac{7}{16}$	$9\frac{3}{4}$ max. $8\frac{1}{4}$ min.	$\frac{7}{8}$	
25 in. (3 Jaw)	25	14·250 14·2485	$4\frac{15}{32}$	$10\frac{21}{32}$	$6\frac{1}{16}$	$4\frac{1}{8}$		$6\frac{1}{2}$	$10\frac{5}{8}$ max. $9\frac{1}{8}$ min.	$\frac{7}{8}$	Used on No. 20 Comb.
25 in. (3 Jaw)	25	14·250 14·2485	$4\frac{15}{32}$	$10\frac{21}{32}$	$6\frac{1}{16}$	$3\frac{1}{2}$		$6\frac{1}{2}$	$7\frac{3}{4}$ max. $6\frac{1}{4}$ min.	$\frac{7}{8}$	Used on No. 50 Auto
32 in. (3 Jaw)	32	14·250 14·2485	$6\frac{3}{8}$	$12\frac{3}{4}$	$6\frac{1}{16}$	$5\frac{1}{4}$	$\frac{5}{32}$	8	$11\frac{1}{4}$ max. $9\frac{3}{4}$ min.	$\frac{7}{8}$	

Size of Chuck	*L*	*M*	*N*	*O*	*P*	*Q*	*R*	
	in.	*in.*	*in.*		*in.*	*in.*	*in.*	
9 in. (2 or 3 Jaw)	$5\frac{11}{16}$ max. $4\frac{15}{16}$ min.	1·12525 1·12475	$1\frac{5}{16}$	$3-\frac{1}{2}$ in. Whit. $1\frac{1}{4}$ in. deep	$\frac{3}{16}$	$2\frac{3}{8}$	$\frac{1}{16}$	
12 in. (3 Jaw)	$5\frac{7}{8}$ max. $5\frac{1}{8}$ min.	1·50075 1·49975	$1\frac{13}{16}$	$3-\frac{1}{2}$ in. Whit. $1\frac{3}{16}$ in. deep	$\frac{3}{16}$	$2\frac{15}{16}$	$\frac{1}{16}$	
15 in. (3 Jaw)	$12\frac{7}{16}$ max. $10\frac{15}{16}$ min.	2·12575 2·12475	$2\frac{5}{16}$	$3-\frac{3}{4}$ in. Whit. $1\frac{1}{4}$ in. deep	$\frac{11}{32}$	$4\frac{1}{8}$	$\frac{3}{32}$	
18 in. (3 Jaw)	13 max. $10\frac{1}{2}$ min.	2·12575 2·12475	$2\frac{5}{8}$	$3-\frac{3}{4}$ in. Whit. $1\frac{1}{8}$ in. deep	$\frac{11}{32}$	$5\frac{1}{16}$	$\frac{3}{32}$	
21 in. (3 Jaw)	$13\frac{9}{16}$ max. $12\frac{1}{16}$ min.	3·251 3·2495	$3\frac{7}{8}$	$6-\frac{7}{8}$ in. Whit. $1\frac{3}{4}$ in. deep	$\frac{11}{32}$	$5\frac{13}{16}$	$\frac{3}{32}$	
25 in. (3 Jaw)	$14\frac{1}{2}$ max. 13 min.	3·251 3·2495	$3\frac{7}{8}$	$6-\frac{7}{8}$ in. Whit. $1\frac{3}{4}$ in. deep	$\frac{9}{32}$	$7\frac{1}{8}$	$\frac{3}{32}$	Used on No. 20 Comb.
25 in. (3 Jaw)	$11\frac{5}{8}$ max. $10\frac{1}{8}$ min.	2·12575 2·12475	$2\frac{5}{8}$	$6-\frac{7}{8}$ in. Whit. $1\frac{3}{4}$ in. deep	$\frac{9}{32}$	$7\frac{1}{8}$	$\frac{3}{32}$	Used on No. 50 Auto
32 in. (3 Jaw)	$15\frac{3}{4}$ max. $14\frac{1}{4}$ min.	3·251 3·2495	$4\frac{1}{2}$	$6-\frac{7}{8}$ in. Whit. $1\frac{3}{4}$ in. deep	$\frac{9}{32}$	$9\frac{1}{4}$	$\frac{1}{8}$	

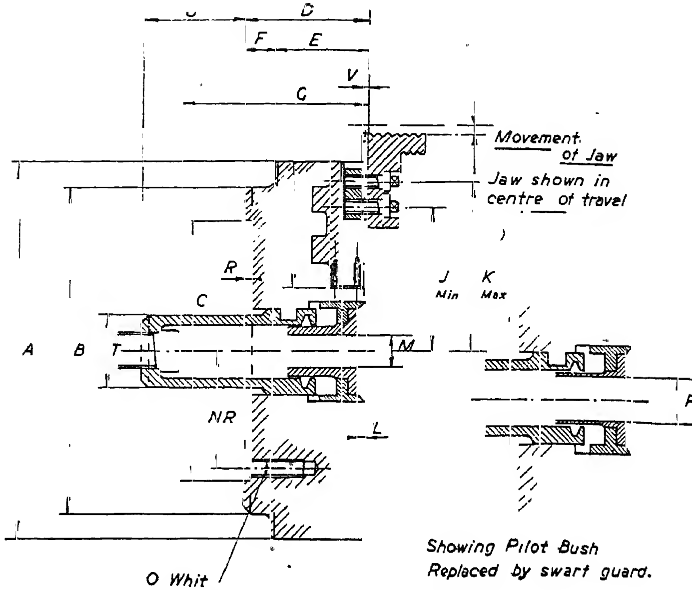
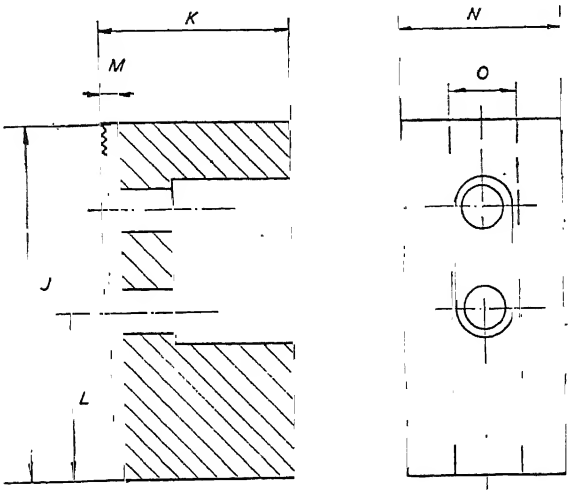


Fig. 33.—Herbert air chucks. 6-in. and 7½-in.

HERBERT AIR CHUCK—6-IN. AND 7½-IN.

Size of Chuck	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*
6 in. 2 or 3 Jaw	*in.* 6¼	*in.* 5¾	*in.* 5·250 5·249	*in.* 2⅜	*in.* 1¾	*in.* ⅝	*in.* 3⅞ max. 3⅜ min.	*in.* 2 1/32	*in.* 1¼	*in.* 2 15/16
7½ in. 2 or 3 Jaw	7½	6⅝	5·250 5·249	2⅜	1 27/32	17/32	3⅞ max. 3⅜ min.	2 9/16	1⅜	3 9/16

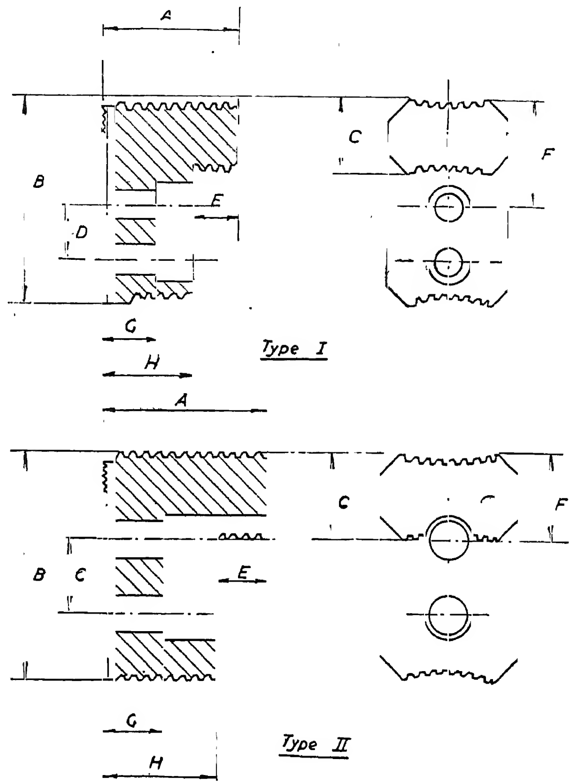
Size of Chuck	*L*	*M*	*N*	*O*	*P*	*R*	*S*	*T*	*U*	*V*
6 in. 2 or 3 Jaw	*in.* 7/64	*in.* 0·50025 0·49975	*in.* 2 11/32	3—½-in. Whit. 13/16 in. deep	*in.* ¾	*in.* 3/16	*in.* ⅛	*in.* 1 7/16	*in.* 2¼ max. 1¾ min.	*in.* 1/16
7½ in. 2 or 3 Jaw	7/64	0·62525 0·62475	2 11/32	3—⅜-in. Whit. 13/16 in. deep	⅞	3/16	⅛	1 7/16	2¼ max. 1¾ min.	1/16



HERBERT AIR CHUCK—SOFT JAWS

Size of Chuck	*J*	*K*	*L*	*M*	*N*	*O*
in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
6	$2\frac{1}{8}$	$1\frac{15}{64}$	1	$\frac{1}{8}$	1	0·502 0·500
$7\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{15}{64}$	1	$\frac{1}{8}$	1	0·502 0·500
9	$2\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{5}{16}$	$\frac{5}{32}$	$1\frac{5}{16}$	0·627 0·625
12	3	2	$1\frac{11}{32}$	$\frac{5}{32}$	$1\frac{1}{2}$	0·689 0·687
15	$3\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{9}{16}$	$\frac{5}{32}$	$1\frac{3}{4}$	0·815 0·812
18	$4\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{13}{16}$	$\frac{3}{16}$	$2\frac{1}{8}$	1·003 1·001
21	$5\frac{3}{8}$	3	$2\frac{1}{16}$	$\frac{1}{4}$	$2\frac{1}{4}$	1·003 1·001
25	$6\frac{1}{4}$	$3\frac{1}{4}$	$2\frac{1}{2}$	$\frac{5}{16}$	$2\frac{1}{4}$	1·003 1·001
32	$7\frac{3}{4}$	4	$3\frac{1}{4}$	$\frac{3}{8}$	$2\frac{7}{8}$	1·253 1·251

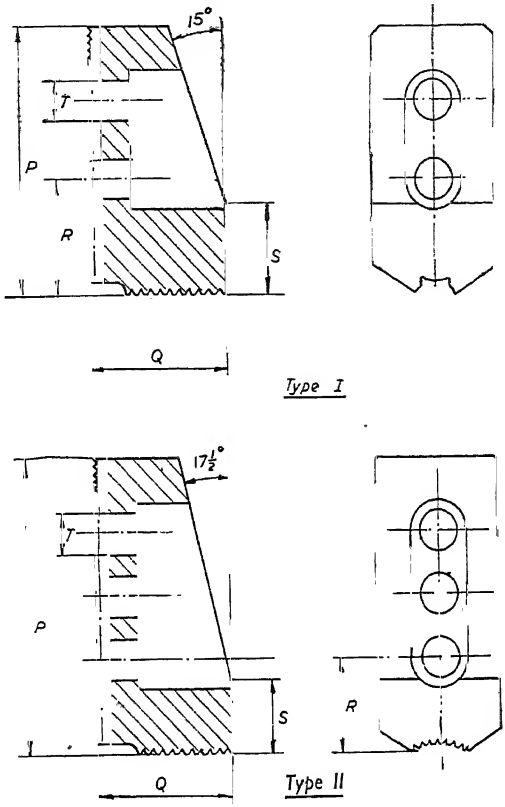
Fig. 34.—Soft jaws for Herbert air chuck.



HERBERT AIR CHUCK—HARD JAWS

Size of Chuck	A	B	C	D	E	F	G	H	Type of Jaw
in.	in.	in.	in.	in.	in.	in.	in.	in.	
6	$1\frac{7}{64}$	$1\frac{1}{2}$	$1\frac{13}{32}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{29}{64}$	$\frac{23}{64}$	$\frac{47}{64}$	I
$7\frac{1}{2}$	$1\frac{7}{64}$	$1\frac{7}{8}$	$\frac{13}{32}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{23}{32}$	$\frac{23}{64}$	$\frac{47}{64}$	I
9	$1\frac{9}{16}$	$2\frac{11}{32}$	$1\frac{1}{16}$	$\frac{5}{8}$	$\frac{1}{2}$	$1\frac{1}{32}$	$\frac{9}{16}$	$1\frac{5}{16}$	II
12	$1\frac{7}{8}$	$2\frac{7}{8}$	$1\frac{1}{4}$	$\frac{29}{32}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{17}{32}$	$1\frac{1}{8}$	II
15	$2\frac{3}{16}$	$3\frac{25}{32}$	$1\frac{19}{32}$	$1\frac{3}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{11}{16}$	$1\frac{3}{8}$	II
18	$2\frac{7}{16}$	$4\frac{1}{2}$	$1\frac{49}{64}$	$1\frac{3}{8}$	$\frac{7}{8}$	1	$\frac{3}{4}$	$1\frac{9}{16}$	II
21	$2\frac{11}{16}$	$5\frac{3}{8}$	2	$1\frac{5}{8}$	1	$1\frac{3}{16}$	$\frac{27}{32}$	$1\frac{1}{16}$	II
25	$2\frac{15}{16}$	$6\frac{15}{32}$	$2\frac{9}{16}$	$2\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{13}{32}$	$\frac{27}{32}$	$1\frac{3}{16}$	II
32	$3\frac{5}{8}$	$7\frac{11}{16}$	$2\frac{31}{32}$	$2\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{9}{16}$	$1\frac{1}{8}$	$2\frac{1}{8}$	II

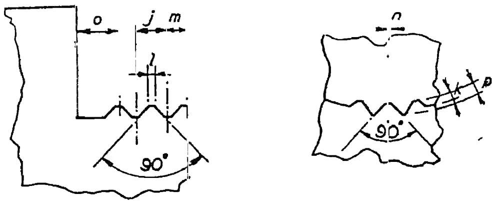
Fig. 35.—Hard jaws for Herbert air chuck.



HERBERT AIR CHUCK—BAR JAWS

Size of Chuck	P	Q	R	S	T	Type of Jaw
in.	in.	in.	in.	in.	in.	
6	$2\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{3}{16}$	$\frac{31}{32}$	$\frac{21}{64}$	I
$7\frac{1}{2}$	$2\frac{5}{16}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{21}{64}$	I
9	$3\frac{19}{64}$	$1\frac{9}{16}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{15}{32}$	II
12	$4\frac{9}{32}$	$1\frac{13}{16}$	$1\frac{7}{32}$	$\frac{7}{16}$	$\frac{17}{32}$	II
15	$5\frac{19}{64}$	$2\frac{7}{32}$	$1\frac{17}{32}$	$\frac{1}{2}$	$\frac{21}{32}$	II
18	$6\frac{5}{16}$	$2\frac{19}{32}$	$1\frac{49}{64}$	$\frac{11}{16}$	$\frac{25}{32}$	II
21	$7\frac{11}{32}$	$3\frac{7}{64}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{25}{32}$	II
25	$7\frac{59}{64}$	$3\frac{1}{8}$	$1\frac{7}{16}$	$\frac{15}{16}$	$\frac{25}{32}$	II
32	$9\frac{1}{4}$	$4\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{32}$	II

Fig. 36.—Bar jaws for Herbert air chuck.



SERRATIONS

j	k	l	m	n	o	p
$\frac{5}{32}$	$\frac{3}{64}$	$\frac{3}{64}$	[illegible]	$\frac{1}{32}$	$\frac{9}{64}$	$\frac{1}{16}$
$\frac{5}{32}$	$\frac{3}{64}$	$\frac{3}{64}$	[illegible]	$\frac{1}{32}$	$\frac{9}{64}$	$\frac{1}{16}$
$\frac{5}{32}$	$\frac{3}{64}$	$\frac{3}{64}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{9}{64}$	$\frac{1}{16}$
$\frac{3}{16}$	$\frac{3}{64}$	$\frac{3}{64}$	$\frac{5}{32}$	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{16}$
$\frac{7}{32}$	$\frac{3}{64}$	$\frac{3}{64}$	$\frac{7}{32}$	$\frac{1}{32}$	$\frac{1}{4}$	$\frac{1}{16}$
$\frac{1}{4}$	$\frac{5}{64}$	$\frac{5}{32}$	$\frac{7}{32}$	$\frac{1}{32}$	$\frac{5}{16}$	$\frac{3}{32}$
$\frac{5}{16}$	$\frac{5}{64}$	$\frac{3}{64}$	$\frac{1}{4}$	$\frac{1}{32}$	[illegible]	$\frac{1}{8}$
$\frac{9}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{1}{32}$	[illegible]	$\frac{1}{8}$
$\frac{9}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{7}{32}$	$\frac{1}{32}$	$\frac{9}{32}$	$\frac{1}{8}$

Fig. 37.—Jaw serrations for Herbert Coventry chuck.

Mottling Surfaces.—For the mechanical method as employed on faceplates and machine tools, the articles are finished dead smooth first, then, with a tool similar to the ground-off end of a broken file (ground with a cutting edge), take off an infinitesimal portion of the surface of the plate or other article. The tool is held at an angle of about 35° to 40°, and the operator uses either a circular motion or an irregular backward-and-forward motion. The work is continued until the whole surface of the plate, etc., is beautifully mottled with wavy lines or patches as desired. A chemical method of producing a mottle of brown and green is to subject the thoroughly clean work to the action of a boiling solution of 8 oz. copper sulphate and 2 oz. sal-ammoniac in 1 gall. of water. When a brownish colour appears, transfer the work to a solution (cold) of 4 oz. salsoda in 1 gall. of water, floating on the surface of which second solution is some oil or petrol. On replacing the work in the first solution a green colour appears; but, owing to the oil which spreads over the surface of the work, the actions of the two solutions are not even, and the colours become mixed.

SCREW THREAD TERMS

Certain terms have been standardised in connection with screw threads, and they are here listed:

Angle of Thread.—The angle of thread is the angle included between the sides of the thread, measured in an axial plane.

Axis of Thread.—The longitudinal central line through the screw from which all corresponding parts are equally distant.

Basic Size.—The theoretical or nominal standard size from which all variations are made.

Clearance.—Defined on thread gauges as the relief in the minor diameter of plug gauges and the major diameter of ring gauges, such as, for example, exists in "effective diameter" gauges.

Convolution,—One full turn of a screw.

Core Diameter.—See Minor Diameter.

Crest.—The top surface joining the two sides of a thread.

Depth of Engagement.—The depth of a thread in contact with two mating parts—measured radially.

Depth of Thread.—The depth of thread, in profile, is the distance between the crest and the root of the thread measured normal to the axis.

Drunken Thread.—A thread in which the advance of the helix is irregular in every convolution.

Effective or Pitch Diameter.—On a parallel screw thread the pitch diameter is the diameter of an imaginary cylinder which would pass through the threads at such points as to make the width of the thread at these points equal.

Flank Angles.—The angles between the flanks of a thread and a plane perpendicular to the axis, measured in an axial plane.

Flank of Thread.—The surface of the thread which connects the crest with the root.

Full Diameter.—See Major Diameter.

Helix Angle.—The angle made by the helix of a thread at the pitch diameter with a plane perpendicular to the axis.

Lead.—The distance a screw thread advances axially in one turn. On a single thread the lead and pitch are identical. On a double thread the lead is twice the pitch; on a triple thread the lead is three times the pitch, etc.

Length of Engagement.—The length of contact between two mating parts measured axially.

Limits.—The extreme sizes which are prescribed for any dimension to provide variations in fit and workmanship.

Major Diameter.—On a parallel screw thread the major diameter is the largest diameter of the thread on the screw or nut. The term "major" replaces the term "outside diameter" as applied to the thread of a screw and also the term "full diameter" as applied to the thread of a nut.

Minor Diameter.—On a parallel screw thread the minor diameter is the smallest diameter of thread on the screw or nut; the root diameter. The term "inside diameter" is usually applied to the smallest diameter of a nut.

Number of Threads.—The number of threads in a length of 1 in.

Outside Diameter.—See Major Diameter.

Pitch.—The distance from a point on a screw thread to a corresponding point on the next convolution of the thread measured parallel to the axis. The pitch equals 1 divided by the number of threads per inch.

Pitch Diameter.—See Effective Diameter.

Root.—The bottom surface joining the sides of two adjacent threads.

Root Diameter.—See Minor Diameter.

Screw Thread.—A screw thread is a ridge of some desired profile generated in the form of a helix on the inside or outside of a cylinder or cone.

Thread, Single.—A thread in which the lead is equal to the pitch.

Thread, Double.—A thread in which the lead is equal to twice the pitch.

Thread, Triple.—A thread in which the lead is equal to three times the pitch.

Thread, Quadruple.—A thread in which the lead is equal to four times the pitch.

(*Note.*—When ordering tools with multiple threads, both pitch and lead should be stated.)

Tolerance.—The difference between the limits or maximum and minimum sizes specified for a given dimension of a part or gauge. A tolerance may be expressed as plus or minus or both, with reference to the basic size. A total tolerance is the sum of a plus and minus tolerance.

Force Exerted by Screw.—To determine the force exerted by a screw:

Let P = pitch of screw.
r = radius on which force acts.
$\pi = 3{\cdot}1416$.

$$F : W = P : 2\pi r. \qquad F = \frac{WP}{2\pi r}. \qquad W = \frac{F 2\pi r}{P}.$$

B.S. SPECIFICATIONS FOR BOLTS, NUTS, RIVETS

The British Standards Institution publish the following specifications for screw-threads:

B.S. No. 28, 1932. Black Bolts and Nuts, Studs, Lock Nuts and Washers (B.S.W.), Dimensions of.

B.S. No. 57, 1920. Heads for British Association Screws.

B.S. No. 190, 1924. British Standard Whitworth (B.S.W.) Bright Hexagon Bolts, Nuts, Set-screws, Split-pins, Washers and Studs, Dimensions. (Add. June 1928 and Sept. 1932.) (Under Revision.)

B.S. No. 190C, 1924. Ditto, ditto. (Issued as Wall Chart, 21 in. × 33 in.) (1s., 1s. 3d.)

B.S. No. 191, 1924. British Standard Fine (B.S.F.) Bright Hexagon Bolts, Nuts, Set-screws, Split-pins, Washers and Studs, Dimensions. (Add. Sept. 1932.)

B.S. No. 191C, 1924. Ditto, ditto. (Issued as Wall Chart, 21 in. × 33 in.) (1s., 1s. 3d.)

B.S. No. 193, 1929. British Standard Whitworth Small Hexagon (B.S.W.S.) Bright Hexagon Bolts, Nuts and Set-screws, Split-pins, Washers and Studs. (Add. Sept. 1932.)

B.S. No. 325, 1928. Black, Iron and Steel, Cup and Counter-sunk Bolt-heads, Nuts and Washers, Dimensions. (Add. June 1940.)

B.S. No. 425, 1931. Forms and Dimensions of Boiler Rivets (as Manufactured) (½ in. to 2 in. diameter).

B.S. No. 450, 1932. Bright Counter-sunk, Round, and Cheese-head Screws (B.S.W. and B.S.F.).

B.S. No. 451, 1932. Bright Square-head Set-screws (with Flat Chamfered Ends) (B.S.W. and B.S.F.).

B.S. No. 641, 1935. Dimensions of Small Rivets (Ferrous and Non-Ferrous, of Nominal Diameters below ½ in.) for General Purposes. (Add. Dec. 1936.)

B.S. No. 768, 1938. Grub Screws (B.S.W., B.S.F., B.A., and B.S.P.).

B.S. No. 856, 1930. Wing Nuts.

B.S. No. 916, 1940. Black Bolts and Nuts (Small Hexagon and Square) (B.S.W. and B.S.F.), Dimensions of.

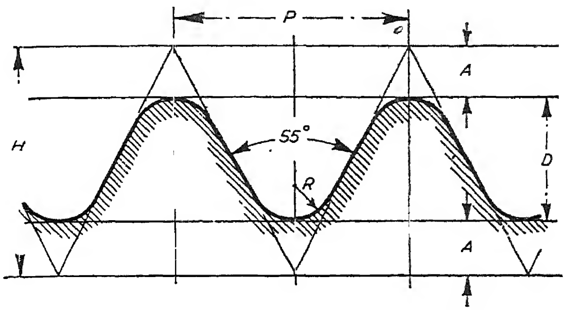


Fig. 1.—The British Standard Whitworth Thread.

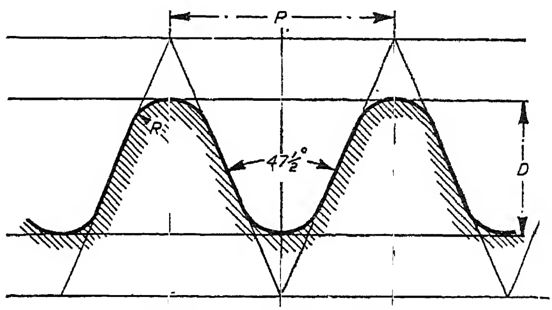


Fig. 2.—British Association Standard Thread (B.A.).

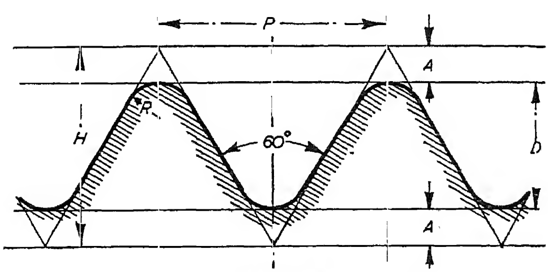


Fig. 3.—British Standard Cycle Thread (B.S.C.).

B.S. SPECIFICATIONS FOR SCREW THREADS

B.S. No. 2E.9. Sparking Plugs for Aircraft Engines.
B.S. No. 16, 1937. Screw Threads for Telephone Wire Cup Fittings.
B.S. No. 21, 1938. Pipe Threads, Part 1. Basic Sizes and Tolerances.
B.S. No. 84, 1940. Screw Threads of Whitworth Form (Incorporating B.S. 92). (5s., 5s. 4d.)
B.S. No. 93, 1919 (formerly C.L. 7271). Screw Threads (British Association), with Tolerances for sizes Nos. 0 to 15 B.A. (Superseding No. 20.) (Add. Aug. 1940.)
B.S. No. 95, 1919. Correction to Effective Diameter required to compensate Pitch and Angle Errors in Screw Threads of Whitworth Form, Tables of.
B.S. No. 98, 1934. Edison-type Screw Lamp Caps and Lamp Holders.
*B.S. No. 164, 1924. Limits and Fits for Engineering.
*B.S. No. 164. Supplement Limits and Fits for Engineering, Metric Units. (1s., 1s. 3d.)
B.S. No. 811, 1938. British Standard Cycle (B.S.C.) Threads.
B.S. No. 870, 1939. Micrometers (External).
B.S. No. 919, 1940. Screw Thread Gauge Tolerances.
B.S. No. 949, 1941. Screwing Taps.
B.S. No. 959, 1941. Internal Micrometers.

"Add." signifies that an Addendum or Corrigendum is issued with this Standard.
* Wartime issue, July, 1941.

THREAD FORMS

Sir Joseph Whitworth evolved the first standard thread after much study and comparisons of the numerous types in use. Many other standards existed for some time, but had to give way to the present moderate number which are designed to suit the varying conditions of heavy and light service, as well as features concerning adjustments, and special requirements as to durability. There are some special shapes of thread for the more unusual requirements, but whenever possible it is best to employ the standard types, for which cutting-tools are readily available, and for which replacements may be obtained easily.

Standard Threads.—The original conception of a thread, the vee shape, occurs in several standards of different angles. The sharp terminations are objectionable because the tops become liable to injury, and the roots are a source of weakness, consequently the latter are finished with a flat and the tops left sharp for a certain pipe standard, but in all other cases rounding or flattening is done at root and crest.

Whitworth Thread (B.S.W.). This (Fig. 1), the most extensively employed type, embodies the formula:

$$P = \text{Pitch} = \frac{1}{\text{No. of threads per in.}}$$

$$H = \text{Theoretical depth} = 0{\cdot}9605 \times P.$$

$$D = \text{Actual depth} = 0{\cdot}6403 \times P.$$

$$\text{Truncation or shortening} = A = \frac{H}{6} = 0{\cdot}1601 \times P.$$

$$\text{Depth of rounding at crest and root} = 0{\cdot}73917P.$$

$$\text{Radius at crest and root} = R = 0{\cdot}1373 \times P.$$

Other Whitworth shape standards vary in the number of threads per inch, and include British Standard Fine Threads (B.S.F.), Whitworth Watch and Instrument, specified by the number indicating the size of screw, Whitworth Pipe Threads, and British Standard Pipe Threads (B.S.P.).

British Association (B.A.).—This is for small work, optical, camera, clock, model, telegraph, and such like, the sizes being designated by numbers. The form is seen in Fig. 2, and the formula is:

$$D = 0{\cdot}6P.$$

$$R = \frac{2}{11} P.$$

$$\text{Double depth of thread} = \frac{6}{5}\text{pitch}.$$

Pitch $= 0{\cdot}9^n$ (millimetres) where n is the designating number of the screw.

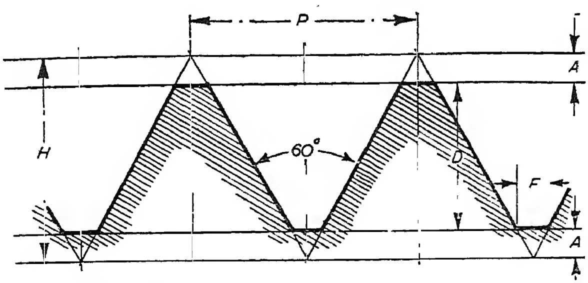


Fig. 4.—Sellers' or United States Standard Thread (U.S.S.).

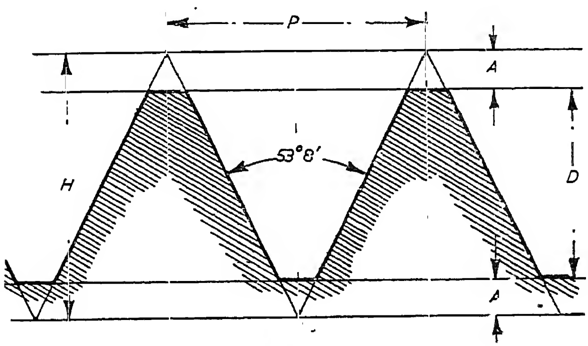


Fig. 5.—Loewenherz Standard Thread.

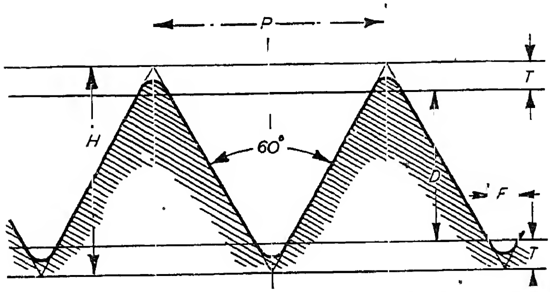


Fig. 6.—Systeme Internationale Standard Thread (S.I.).

British Standard Cycle (B.S.C.).—A fine thread also suitable for models, differs in angle (Fig. 3) from the preceding standards, and has proportions :

H = Theoretical depth = $0{\cdot}866 \times P$.
D = Actual depth = $0{\cdot}5327 \times P$.
A = Rounding at crest and root = $0{\cdot}166 \times P$.
R = Radius at crest and root = $0{\cdot}166 \times P$.

Sellers' or American Standard (U.S.S.).—This (Fig. 4) and National Fine (N.F.), the same thread shape being used in the older S.A.E. and A.S.M.E. standards.

The formula is :

H = Theoretical depth = $0{\cdot}866 \times P$.
D = Actual depth = $0{\cdot}6495 \times P$.
F = Width of flat = $0{\cdot}125 \times P$.
A = Depth of flat = $0{\cdot}108 \times P$.

There are continental metric systems which follow the flatted vee shape, including French, Swiss, and German, the last-named being the :

Loewenherz.—The angle (Fig. 5) differs from the U.S.S., and the proportions are :

H = Theoretical depth = P.
D = Actual depth = $0{\cdot}75 \times P$.
A = Depth of flat = $0{\cdot}125 \times P$.

Système Internationale (S.I.).—This is another metric thread, differing from all others by having the crests flat and the roots rounded (Fig. 6), with formula :

$$H = 0{\cdot}866 \times P.$$
$$D = 0{\cdot}6495 \times P.$$
$$F = 0{\cdot}125 \times P.$$
$$T = 0{\cdot}108 \times P.$$

Pipe and Sparking-plug Threads.—The Whitworth Pipe Thread and the British Standard Pipe Thread (B.S.P.) carry the same shape and proportions of thread as the other Whitworth standards. The Briggs, now the American National Taper Pipe Thread, is of 60-degree angle with sharp crests, and has $\frac{1}{32}$ in. of taper per inch, the same as the B.S.P. Sparking-plug tap threads are, variously, ½ in. gas, 18 mm. diam. by 1·5 mm. pitch ; 14 mm. by 1·25 mm. ; and Briggs ½ in. pipe.

Square Threads.—These have been largely supplanted by the sloping side threads, of the Acme shape, which are easier to cut, and are convenient when easy disengagement of a nut is required. Proportions are (Fig. 7) :

$$D = 0{\cdot}5 \times P.$$
$$W = 0{\cdot}5 \times P.$$

Acme Threads.—This strong modification of the square thread resembles the worm thread in angle, but is shallower (Fig. 8) :

$$D = 0{\cdot}5 \times P + 0{\cdot}010 \text{ in.}$$
$$B = 0{\cdot}37 \times P - 0{\cdot}0052 \text{ in.}$$
$$C = 0{\cdot}37 \times P.$$

It is not essential to use a full-depth thread for a great many kinds of service, half or two-thirds being sufficient ; many sorts of unions of parts and adjusting devices being so made.

Worm Threads.—These, deeper than the Acme, may have the angles radiused (Fig. 9). Worms are tricky things to produce accurately, either in the lathe or by milling, as unless proper knowledge of the action of the tool or cutter is certain, the shape obtained may not be that anticipated.

Miscellaneous Threads.—There is no standard for the Buttress Thread A (Fig. 11), but 45-degree slope is usual, and the form is very strong to resist thrust in one direction. The modified style at B is also good for certain functions. At

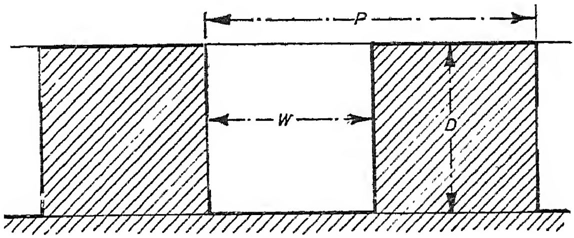


Fig. 7.—Square Thread.

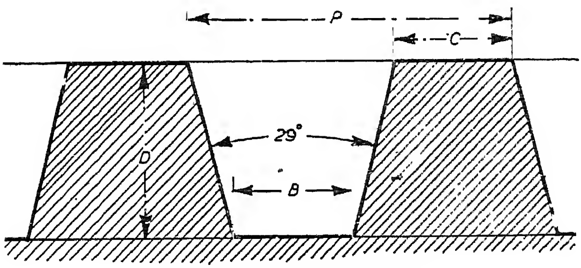


Fig. 8.—Acme Standard Thread.

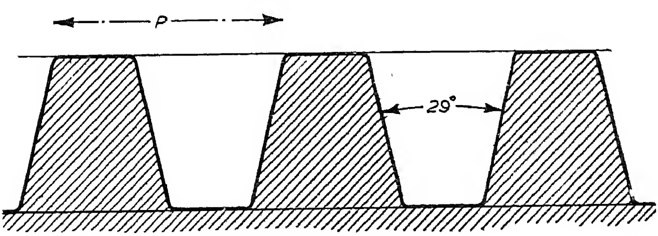


Fig. 9.—Worm Thread.

C the shallow Acme type previously noted is shown, while D is the knuckle thread, employed for some rapid kinds of connections.

There are several special screw threads including the Cordeaux, which has been developed by the G.P.O. and is used exclusively on telephone wire cup fittings, the porcelain cup mating up to the cup fitting and anchored on the felt washer. This is dealt with in B.S. Specification No. 16, 1937. There is also the roll thread for Edison-type screw lamp caps and lamp holders as fitted to electric light. This screw thread is dealt with in B.S. Specification No. 98, 1934.

Aero Thread.—In high-speed engines, especially of the type used for aircraft where screwed and other parts are subjected to especially onerous vibration and repetitions of stress, failures have frequently developed in such screwed fastenings. One cause of fatigue is the presence of sharp corners, notches, and grooves.

A new system named the "Aero thread," having a rounded thread root and employing a spirally wound bushing, has been produced to overcome this difficulty.

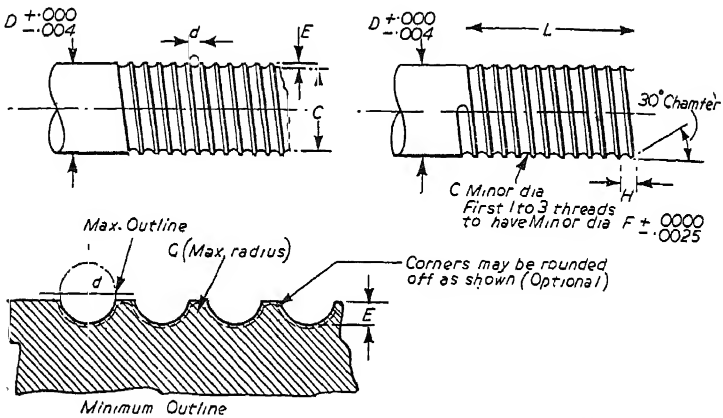


Fig. 10.—The screw, bushing, and tapped hole of the Aero thread (see Fig. 11a).

Fig. 10 shows the screw, bushing, and tapped hole of such an assembly. The bushing or insert, which is an outstanding feature of the system, is spirally wound of high-tensile stainless steel or bronze spring wire, and fits into the previously tapped hole. The latter has a coarse-pitch V thread, similar in form though not in size to the American National Coarse Thread, and the assembly is so designed that it becomes to all intents and purposes a fixed part of the tapped hole.

The screw member employs the new thread form, which, as shown in Fig. 11*a*, has a shallow round bottom thread groove which fits the corresponding form on the inner side of the insert.

The heat treatment of any steel part containing sharp corners is always liable to produce hardening cracks which may lead to eventual failure. While the radius at the root of the Whitworth thread greatly reduces this tendency during hardening, the much larger radius which is employed on the screw member in the Aero-thread system is even more effective in this direction.

Aero-thread set-screws made of heat-treated alloy steel are used where maximum tensile strength is required, but set-screws of heat-treated aluminium alloy can be employed where light weight is important, as the aluminium-alloy Aero-thread set-screw has about the same strength as steel screws with standard American thread.

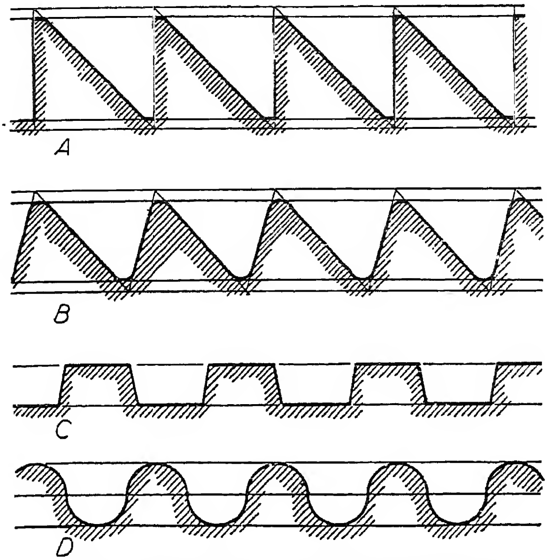


Fig. 11.—A, Buttress Thread ; B, Modified Buttress Thread ; C, Shallow Acme Thread ; D, Knuckle Thread.

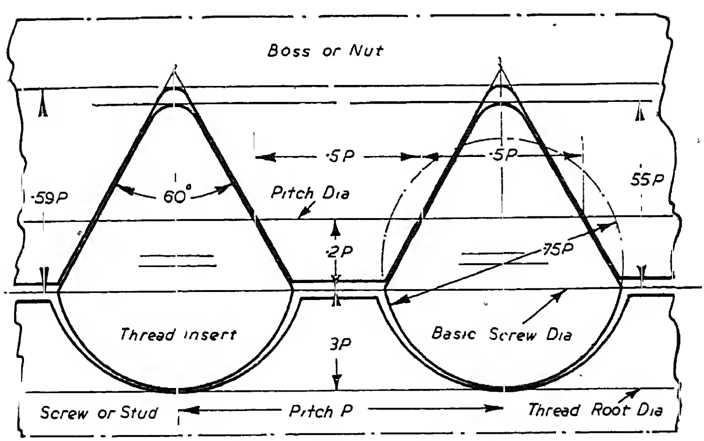


Fig. 11a—New Aero Thread Form.

BOLT AND SCREW MANUFACTURE

On p. 542 is given a list of the various types of bolts, screws, and nuts most commonly manufactured, with an indication of the steels most used in their manufacture. In connection with these various steels a few explanatory notes may be advisable. Steel No. 2 is employed for a certain number of commercial bolts manufactured by the process known as cold heading. These bolts are not required to be excessively strong. The tensile strength is at least 50,000 lb. per sq. in. for the raw material, but the actual tensile strength of the bolts made from it will largely depend on the dimensions of the stock, the method by which the bolt is made, and the heat treatment to which it is subjected. As a rule, this material is employed for bolts that are case-carburised.

Steel No. 6 is employed for mainly the same applications as Steel No. 1, but in this instance the bolts are usually made from it on the screwing machine. Bolts, etc., milled from cold-drawn bars of this steel will show an approximate yield point of 70,000 lb. and ultimate strength of 80,000 lb. per sq. in There is little difference between yield point and tensile strength when the steel is in the cold-drawn condition.

Cold-punched Nuts.—The same steel, then, usually made by the open-hearth method is employed for cold-punched nuts.

Steel No. 3 is mainly designed for bolts that have been made by cold heading, but are required to possess a higher degree of strength than is given by bolts made from Steel No. 1. The carbon content has a great influence on the tensile strength, and the latter will vary according to whether the carbon is high or low. The average tensile strength for bolts made from this steel and heat-treated is 80,000 lb. per sq. in., while the yield point is 60,000 lb. per sq. in.

Bolts, etc., made from this steel are usually made by the screwing machine, and the material is provided in the cold-drawn state, when it will be found to give a tensile strength of about 75,000 and a yield point of 60,000 lb. per sq. in. Sometimes the sulphur percentage is slightly increased in order to enable nuts to be cold- and hot-punched from it. Being made by the open-hearth process, this material is sometimes preferred to Steel No. 6, which is mostly made by the Bessemer process.

Steel No. 4 is designed for bolts made by the cold-heading process, but possessing a higher degree of tensile strength, and capable of standing up to conditions of use of the most exacting character. The bolts are usually heat-treated, after which they will give a minimum tensile strength of 100,000 lb. per sq. in., together with high ductility. The elongation will be at least 12 per cent. in 2 in., and the reduction of area 45 per cent. The Brinell number varies between 196–269, and will suit the majority of jobs. This is steel with the lowest percentage of carbon that can be effectively double heat-treated to fine limits. The same material can also be employed for parts made on the screwing machine.

Fatigue and Shock.—Steels Nos. 1 and 10 are employed when the parts have to withstand fatigue and shock, and after heat treatment are required to furnish a minimum of 125,000 lb. per sq. in. tensile strength. When properly heat-treated, they will give a yield point of 110,000 lb. per sq. in., a tensile strength of 140,000 lb., an elongation of 16 per cent. in 2 in., and a reduction of area of 55 per cent. The Brinell numbers can be within the following ranges: 228–269, 241–286, and 269–321.

Stainless, rust and corrosion resistant, and non-ferrous materials are also employed for making bolts, etc.

The various manufacturing processes may now be briefly outlined. Cold heading is a form of upsetting by means of which the steel is caused to flow into different forms while still in the cold state. Two different types of cold-heading machines are employed: those using solid dies and those using open dies. Normally, the solid-die type is employed for short bolts, etc., and sometimes for those of medium length in which a high quality of finish is required with fine tolerances. The open-die machine is mainly used for long products that cannot be properly dealt with in the solid-die machine. Both forms of apparatus are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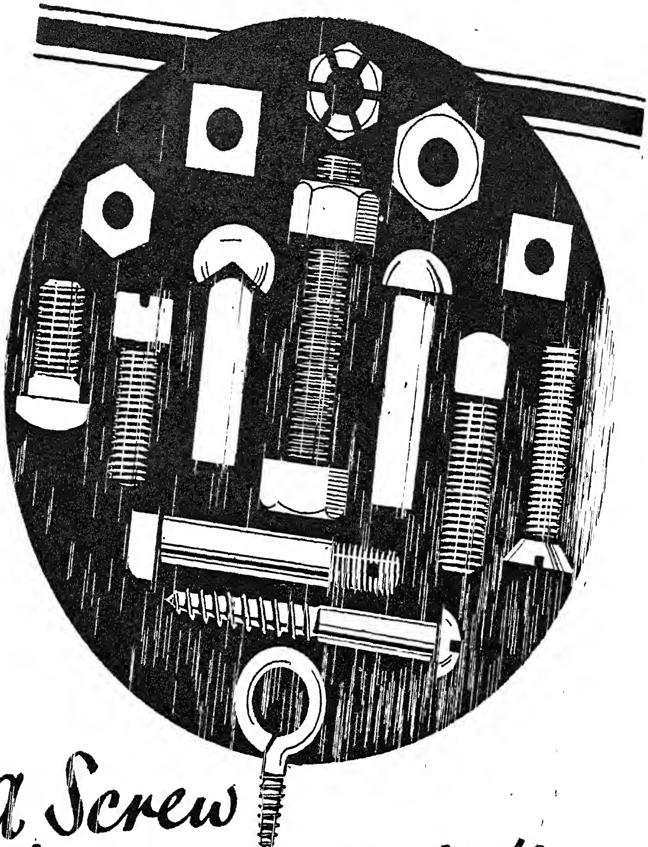


constructed to function with a single stroke, or more than one, for the heading operation. The total number of strokes called for is governed by the form of the head and the quantity of stock to be upset. The majority of these machines are constructed so as to feed wire up to ¾ in. in diameter from the coils.

Cold heading is restricted by the construction of the head since the quantity of material that will flow into specific forms is limited. The entire range of steels given on p. 542 can be employed for cold heading with the exception of Nos. 6, 13, and 14.

Hot heading is carried out in a similar manner to cold heading, save that the steel is heated up to a suitable temperature before the operation.

Trimming.—Trimming is a process that involves compelling an upset button-headed part to pass through a die of the desired shape. This method is adopted for parts with round or button-shaped heads previously formed by cold heading, but desired to possess a hexagon or square form.

Burnishing is employed to give a smoother finish on the side of the bolt head, and frequently succeeds the trimming operation. It comprises driving the bolt head through a die of form identical with that of the trimming die, but a little smaller.

Shaving and pointing are finishing operations. When the top and bottom of the heads are not correctly formed by the heading process, it is possible to finish them by a shaving process, comprising the cutting of the top and bottom of the heads to the requisite shape. This method is commonly employed in the manufacture of cap screws. Pointing or chamfering the end of the body of bolts or screws is achieved by means of a fixture which grips the blank and enables the end to be machined to the requisite shape. By means of this process, the blank is made ready for threading and confers on the threaded end of the bolt the correct finish, while making it easier for it to enter a tapped hole.

Thread Rolling.—Roll threading or thread rolling is achieved by causing the material in blank form to revolve between flat or circular dies on whose faces have been machined angular grooves of identical form and lead with the thread to be rolled. These dies provide the thread by removing material from below the pitch diameter of the thread and filling out the crest or ridge of the thread with the material thus removed.

Rolled threads are, of course, now extensively used on commercial metal containers as well as on electric lamp sockets and lamp holders, whilst such threads are universally used on the sockets and bulbs employed in flashlamps and pocket torches. Such rolled threads have been standardised in B.S. Specification No. 98, 1934.

By making a suitable roll it is sometimes possible to retrieve parts which have been rejected because they are undersize; particularly is this so in the case of screw threads cut on non-ferrous metals. The roll is screw cut in the ordinary way to the same pitch as the thread which is undersize, but the sides of the teeth have about half a degree clearance so that the crests of the teeth on the roll push on the root of the undersize threads and thus force metal to the top of the threads. This will make the threads oversize; when a sizing die can be passed over them to bring them to correct size. It is important to note that the threads will not be of strictly accurate form after such rolling operation, and so the method can only be adopted for unimportant work not subject to rigid limits and inspection.

Measurement and Identification of Bolts and Screw Threads.—The length of a bolt or screw is the measurement taken from under the head to the end of the thread, excepting in the case of countersunk screws, in which the length is the overall measurement.

The threads in common use are British Standard Whitworth, British Standard Fine, British Standard Pipe, and British Association, these being, of course, the standards of this country. Those of America are United States Standard or Sellers, Society of Automobile Engineers, and American Society of Mechanical Engineers. The International System Metric Thread is the standard of most Continental countries. In the order named, the threads mentioned, in an abbreviated form, are designated as follows: B.S.W. or Whit., B.S.F., B.S.P., B.A., U.S.S., S.A.E., A.S.M.E., and S.I.

STEELS USED IN BOLT AND SCREW MAKING

Steel No.	*Purpose*	*Composition per cent.*				
		Carbon	*Manganese*	*Nickel*	*Silicon*	
1	Aircraft bolts Machine bolts	0·25–0·35	0·5–0·8	3·25–3·75		
2	Cap screws Carriage bolts Lag screws Machine bolts Machine screws Plough bolts Rim and hub bolts Rivets Set-screws Shackle bolts Step bolts Stove bolts	0·05–0·15	0·3–0·6			
3	Cap screws Carriage bolts Machine bolts Plough bolts Rim and hub bolts Rivets Shackle bolts	0·15–0·25	0·3–0·6			
4	Cap screws Carriage bolts Machine bolts Rim and hub bolts Set-screws	0·3–0·4	0·6–0·9			
5	Cap screws Carriage bolts Lag screws Machine bolts Plough bolts	0·14–0·2	0·6–0·9		0·075–0·15	
6	Cap screws Set-screws Nuts	0·08–0·16	0·6–0·9	(Free-cutting Steel)		
7	Cap screws	0·15–0·25	0·3–0·6			
8	Cap screws Carriage bolts Lag screws Machine bolts Plough bolts Rim and hub bolts Rivets	0·15–0·25	0·6–0·9	(Free-cutting Steel)		
					Chromium	
9	Cap screws	0·3–0·4	1·6–1·9			
10	Cap screws Conn. rod bolts Machine bolts Set-screws	0·3–0·4	0·5–0·8	1·0–1·5	0·45–0·75	
					Silicon	*Molybdenum*
11	Conn. rod bolts	0·5	0·7–0·9		0·2–0·3	0·15–0·25
12	Machine bolts	0·1–0·2	0·3–0·6			
13	Shackle bolts	0·1–0·2	1·0–1·3	(Free-cutting Steel)		
14	Shackle bolts	0·1–0·2	1·3–1·6	(Free-cutting Steel)		
15	Track bolts	0·2–0·3	0·3–0·6			
16	Track bolts	0·35–0·45	0·6–0·9			
17	Nuts	0·08–0·15	0·3–0·9			
18	Nuts	0·1–0·2	0·6–0·9			

Whitworth screws or studs are generally used in soft metal on account of the deep thread afforded by the coarseness of the pitch. B.S.P. threads are used in connection with unions for petrol and oil piping. The nominal diameter of the thread refers to the bore of the piping for which it is suitable, and this practice is followed out in the case of union nuts, which are mostly tapped with this thread. Unions for both $\frac{1}{8}$ in. and $\frac{3}{16}$ in. diameter pipes are tapped $\frac{1}{8}$ B.S.P., although as a warning it should be mentioned that those for $\frac{3}{16}$ in. diameter are sometimes tapped $\frac{7}{8}$ in. diameter × 19 threads per inch.

B.A. threads are used in substitution for B.S.F. in sizes below $\frac{1}{4}$ in. diameter. These run from No. 0, just under $\frac{1}{4}$ in. diameter, to No. 22, about $\frac{1}{64}$ in. diameter, and are in common use on the items comprising instruments and electrical equipment. In this class of work, screws below No. 10 B.A. are seldom used, and therefore need not be considered.

So far as its application is concerned, the S.A.E. thread may be likened to B.S.F. and A.S.M.E. to B.A. As with B.A., the diameters are denoted by numbers: No. 0, the smallest, is about $\frac{1}{16}$ in. diameter, and No. 30, just over $\frac{7}{16}$ in. diameter, the largest.

Of the thread systems mentioned, two only employ the same thread formation. These are Whitworth and B.S.F. For purposes of identification, thread formation may be ignored excepting in the case of the U.S.S. thread, which size for size up to $1\frac{1}{2}$ in. diameter follows Whitworth as to pitch, with only one alteration, which is the $\frac{1}{2}$ in. diameter bearing 13 threads per inch. As distinct from Whitworth, the shape of this thread is shallower on account of the angle being 60 degrees and is flat at the root and crest.

THREAD ROLLING

Thread rolling comprises forming a thread of helical type on a steel or other metal part with the aid of correctly designed rollers or dies. The roller or rollers, which are pressed against the work as it revolves, are cut with the requisite thread, which they accordingly transmit to the part to be threaded, but in the opposite direction.

Where the parts to be threaded are of solid form, such as screws, material will be economised and output increased.

The operation has the effect of cold working the metal, which gives it added strength. When hollow parts are to be threaded, there is a great saving in expense; for if screw cutting were the only possible method of providing the thread, the parts would have to be made much greater in wall thickness to allow for the material to be tooled away, the pace of production would be much slower, and for such articles as threaded caps for bottles, flashlamps, and electric-light bulbs, price would be excessive.

Thread rolling can be carried out in either the lathe, the automatic screw-cutting machine, or in special machines. The general lathe is, however, seldom employed for this work, its only advantage being when special threads are needed that could not be given by a special machine or would be prohibitive in cost.

A great deal of thread rolling is carried out in automatic screw machines, and as a rule the tools employed are similar to those used for knurling. The thread cut on the roller is, of course, opposite in direction to that which it will produce on the rod or part. Thus, if a right-hand thread is desired, the roller will have to have a left-hand thread.

Thread-rolling Formula.—The blank diameter to be thread-rolled is approximately the pitch diameter of the last thread. The external diameter of the threading roller must be greater than the part, and is calculated from the following formula:

OD = pitch diameter of piece to be rolled − half single depth of thread × multiple used.

No fixed multiple appropriate to every type of job can be given, but the threading roller should be of maximum dimensions. The feeds and speeds correspond approximately to those for knurling.

There is a considerable range of special machines employed for thread rolling a wide variety of jobs. Thus certain machines will thread-roll bolts and screws.

Others are designed for thread rolling caps and tubular parts. The special bolt and screw-threading machines use two correctly designed thread-rolling dies having thread impressions on their faces. One of these dies is fixed and the other moves in a plane parallel to the axis of the work and in a direction normal thereto. The dies are of a special hardened steel, and the thread is projected on to them. The blank employed is approximately the pitch diameter of the bolt or screw being made. This method of threading a bolt is probably the most frequently employed, and is advantageous both as regards economy and rate of production. The speed normally varies inversely with the size of bolt or screw being threaded, but is normally in the range of 30–100 pieces a minute.

Sheet-metal Caps.—In thread rolling sheet-metal caps and tubular parts, there is no standardised thread as with bolts and screws, a number of different systems being employed. The only standard thread is that employed in making socket shells for electric-lamp bulbs and similar parts. As a result of this, it is scarcely practicable to provide precise details as to the relation of the shell dimensions to the external diameter or pitch diameter of the threaded part. Furthermore, there is very much more fluctuation in this respect caused by the particular alloy and temper used than with solid parts. The reason is that the physical properties vary considerably as between one alloy and another, and between one temper and another in any one alloy.

Shell diameter is normally rather greater than pitch diameter. The arbor size approximates to that of the blank, and it thus becomes possible to fit the shell on to the arbor, but only just possible. The size of the thread roller is established by subtracting the single depth of thread from the pitch diameter and multiplying by a factor, resembling the method of calculating a roller size for use in the automatic screw machine. On special machines for thread rolling shells, multiples as high as 12 are occasionally employed, but the multiple of 4 is more usual. The arbor and roller are mated through gears, as for knurling. According to the multiple employed, the roller will possess single, double, triple, or quadruple thread. Thus, if the multiple is 2, the roller will be cut with a double thread.

The shell is generally automatically fed to the machine, and automatically discharged on completion of the work. No specific speeds can be quoted, as there is too much variation.

No specific formulæ for blank diameters can be supplied for the different forms of rolled threads; but it remains important, nevertheless, that the correct diameter should be found and maintained, as the result of the operation may depend on how successfully this size is maintained. Usually too small a blank results in a poorly developed thread, and too large a blank produces an oversize thread that is often rough.

Steel for Thread Rolls.—The best steel for the dies for thread rolling is a high-carbon, high-chromium steel. To obtain the best results from this material, it must be most carefully forged, and should be warmed gradually. The temperature should then be raised slowly to 1000° C., but care should be taken not to exceed 1100° C. under any circumstances. Should forging not be completed at this stage, the steel should be heated up again for the additional forging work, and so on until the job is completed. Too severe a size reduction at one stroke should not be essayed.

Normalising to relieve forging strains is advisable after forging and before the steel has had time to cool down completely. Hardening should be carried out at 950° C. in oil, or by heating to 950–980° C. and cooling in still air in a dry place. Annealing the steel for machining should be done at 780–800° C.,the temperature being maintained 2–4 hours, after which slow cooling in the furnace should follow.

The steel should be preheated slowly between 750–800° C., then brought up to 1050° C. and air cooled. Tempering is at 200–250° C. If desired, the material can be oil hardened from 950° C. and tempered at 200–250° C.

Machining out of the threads should not be done at a fast speed nor with a heavy feed, and no lubricant should be employed. High-speed tools are advisable.

THREAD MILLING

The enhanced rate of cutting which is possible when a mill is used instead of a single-point tool, and the greater accuracy often obtainable, explain why this process is so extensively applied. For heavy, long screws and worms the method is very valuable, but it also permits shorter screws to be cut rapidly at one revolution, and in conjunction with facile chucking arrangements and semi-automatic control production is fast. Threads can be cut parallel, tapered, in steps, interrupted, and combined with plain parts, milled by the same cutter. On thin pieces the risks of distortion may often be less than is liable by employing other methods.

Cutting on the Universal Miller.—Screws and worms are milled with the use of the spiral head, tapers requiring a tilt of the head and tailstock. A vertical-spindle attachment drives the cutter, or sometimes a rack-cutting attachment is chosen. In an outfit regularly supplied for thread milling on a twin overarm machine, a massive cutter-head is clamped to the arms and also bolted to the column face by a slotted angle-plate bracket. There is a lateral adjustment along the overarms sufficient to accommodate all angles of table swivel up to 45 degrees. T-slots at the front face of the cutter-head housing enable a follower-rest to be attached, carrying a pad which can be adjusted to come underneath the screw close to the mill. This is a necessity when a screw is too long and slender to withstand cutting pressures.

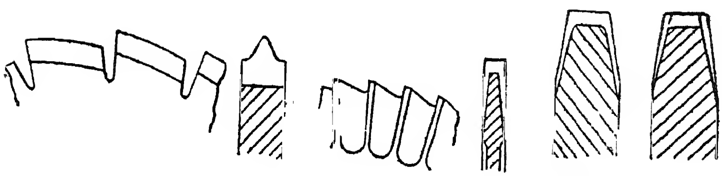


Fig. 12.—Thread-milling cutters for square, acme, worm, and vee threads.

Hobbing.—A good deal of hobbing of multiple-thread worms is done, with the sides of the hob laid out to a suitable curve so as to produce straight flanks to the worm. Production is rapid by this method, and the degree of accuracy may not be particular, because grinding so often follows after the hardening process. The vertical-work-spindle style of hobbing machine is largely utilised for this mode of cutting.

Thread-milling Machines.—Steady-rests are disposed as necessary Another type does not have the travelling rest principle, but the headstock is fed along to pass the blank in front of a fixed cutter-head. A lead or master screw and change gears provide the ratios.

Those machines which complete the operation in a revolution occur in several kinds—small and large, for external, internal, and tapered work. An Archdale for 4½-in. internal and 6-in. external threads by 1½ in. long has a large spindle with cutaway opening at one side, between the bearings, to permit pieces to be inserted in the concentric chuck or special holder, and feed is obtained from a short detachable guide-screw keyed to the rear end of the spindle. A guide-screw and nut are required for each pitch. The spindle stops its rotation automatically after one turn. The cutter-head goes on a saddle regulated along the bed by rack and pinion, and there is a transverse motion to a dead stop, while an additional transverse slide under the head is moved by hand lever to bring the mill into the cutting position, whereupon automatic latching takes place.

A larger size of Archdale machine functions automatically. After chucking the piece, a push-button starts the cycle and the rotation of the cutter and work-spindles. A cam action sinks the cutter into the required depth (determined by a micrometer setting). The work rotates slightly more than a revolution, then the

cutter withdraws and the machine stops. During the revolution the carriage is moved forward by a cam selected to give the specified lead, and returns automatically. In addition to the main push-button on the work-head for starting and stopping three other control switches are installed, one for the cutter-head, a three-way switch for (1) internal threads, (2) cutter-head spindle stop, and (3) the coolant pump.

On a bigger machine of more complex design by another maker a lead screw

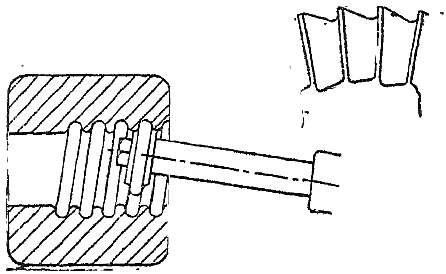


Fig. 13.—Milling a knuckle-thread nut.

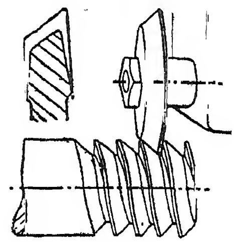


Fig. 14.—Mill for buttress threads.

is used and change gears, with a device to eliminate all backlash. A large hole through the spindle allows long articles to be passed in, and various sorts of chucks can be fitted, usually with wedge motion, suitable liners or blocks being attached according to shape of object. For short components a single air cylinder is placed at the rear end and moves the tube that controls the chuck, but for leaving a clear way throughout twin air cylinders are employed, set on each side of the spindle at the rear, and connecting to a cross-head and ball-bearing ring on the control tube. A taper attachment is arranged, to be altered to suit amounts, and a stop provided to ensure that the relationships of work and taper slide are similar each time, otherwise threads will not match. A hand facing attachment is also mounted, to permit turning and facing to be done. For taps and dies a relieving mechanism acts under compulsion of a cam, and mills and relieves at the same time.

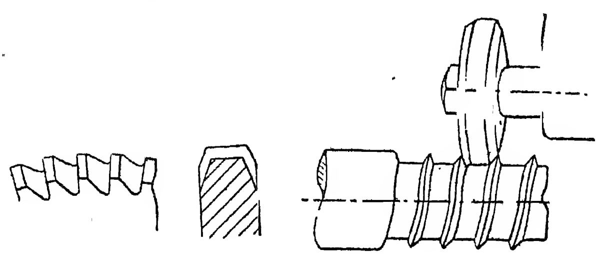


Fig. 15.—Milling a special wood screw.

Worm-milling Machine.—The general construction of this class of machine comprises a fixed cutter-head having angling adjustment for the slope of the mill, and a sliding table with headstock and tailstock, movement being given by lead screw and change wheels. At the end of the stroke the cutter-head withdraws, and the table automatically returns for the indexing, the headstock having apparatus for diving as required, and independent adjustment for remounting partly cut worms. The cutter-spindle may be adjusted endwise for locating the cutter.

Applications of Thread Mills.—The principal types of cutters include those which mill a single groove at a time, those forming a radius on the thread crests as well, multi-thread mills, and those performing a plain milling operation at the same time. Shapes for square, Acme or worm, and vee thread (of backed-off style) are shown in Fig. 12, the last combining the radiusing. The second Acme thread shape has a tooth cut away on alternate sides to afford chip clearance,

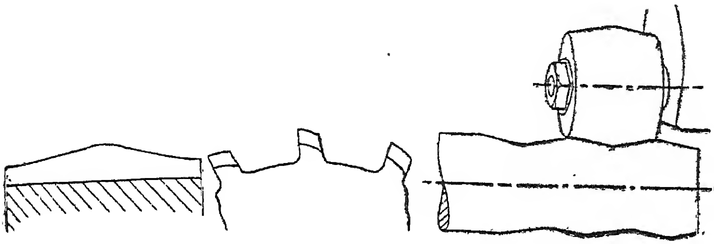


Fig. 16.—Milling a special scroll shape.

one tooth being left full for measuring purposes. Figs. 13 to 15 represent operations on buttress threads, special wood screws and knuckle threads, while Fig. 16 deals with scroll milling. An unusual formation occurs in Fig. 17, the tapers being milled at the same time as the threads. The undercut was done with a turning tool whilst the spindle speed was increased to turning rate. In Fig. 18 the idea is to assemble the nut and screw with a quarter-turn, so the flats were first milled, and in another operation the threads, at settings of 180 degrees. The high tooth at the end of the hob finished the end. The bands are milled in the case of Fig. 19 and afterwards speed increased for the facing tools.

Multiple cutters are used for double- or triple-thread worms if the cost is warranted, such a mill being more expensive than a single-tooth one. Accurate centring is vital (Fig. 20) to ensure threads of uniform thickness.

THREAD GRINDING

The grinding process was originally applied to the finishing of hardened threads required to be very accurate, such as micrometer caliper screws, and they were also originated from the hardened blank. Worm threads were also ground at an early date, but the general developments of the method are relatively recent. Now a great number of pieces are ground from the solid, and various gauges and taps cannot be classed as precision unless finished by the wheel. The earlier difficulties of keeping size and shape are overcome by a more suitable choice of abrasive, and by truing devices which copy the contour of a former many times larger than the screw.

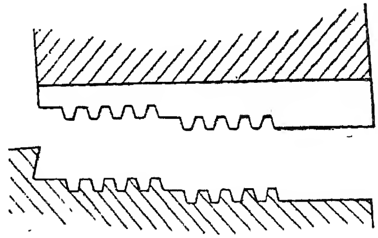


Fig. 17.—Milling a stepped acme thread and plain portions.

Wheel Applications.—Alternative systems of grinding threads may be noted, comprising single-rib and multi-rib wheels, the latter being fed into depth and

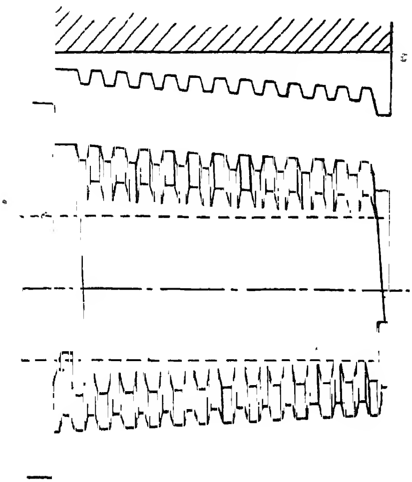


Fig. 18.—Quick-engaging screw, flats milled first, then threads.

traversed for a short distance to complete the thread, two passes being required for coarse threads. A tapered wheel is sometimes employed when the shape of the work permits, traversing right across and gradually deepening the cut, these methods being drawn in Fig. 21. Tandem wheels are sometimes run for roughing and finishing, being pitched apart a suitable distance; one section roughs the thread, then the blank is moved along to get the other wheel into action. Another practice is to use a composite wheel, half of it softer for roughing without undue heating, the other half following and being harder retains its form for a longer period than a soft one would. Internal grinding is performed with an attachment which can be substituted for the ordinary wheel-spindle mounting. Relief grinding for taps and hobs may be effected, also taper-thread grinding.

Work Driving and Feeding.—The connection between drive and feed is usually through lead screw and change gears, but in one case a cam is provided, giving the proper threading ratio and quick return. A set of cams with change gears offers an extensive range of pitches. In lead-screw motions a high-speed return takes place after the quick withdrawal of the wheel. A goodly range of work speeds is necessary, and some machines have all-gear changes, others belt and cone changes, with back-gear for doubling.

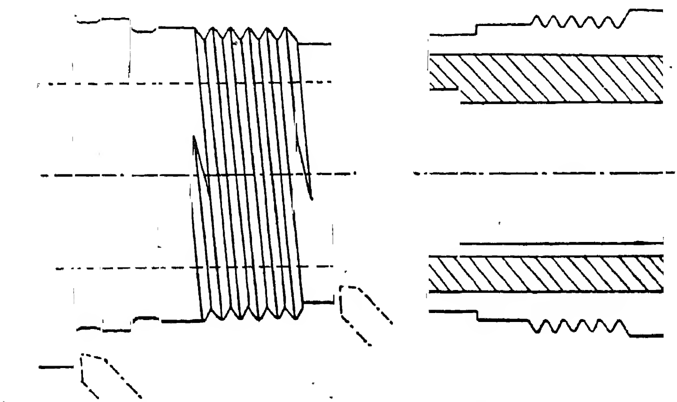


Fig. 19.—The bands are milled with the same cutter, and facing tools operate on the same machine.

Wheel Speeds.—Correct speed is vitally important in thread grinding because

the duty is severe on the wheels, and there is no freedom to pass sections of the wheel from one spot to another in the same manner that occurs with traverse plain grinding. Wrong speed will wear and depreciate the wheel prematurely and spoil the chances of getting a good finish as well. One machine has an instrument calibrated to show the speed of the wheel spindle, and a scale attached to the truing device automatically records the wheel diameter, so that correction can be made according to wear. Work and wheel speeds must bear correct relationships, and the cause of failure of a wheel to cut successfully may be that the work is going too fast, causing heating and breaking up of the wheel edge. On the other hand, too slow work speed will sometimes induce dulling and burning. Much depends on the kind of material being handled, and, of course, the relative hardness of the wheel.

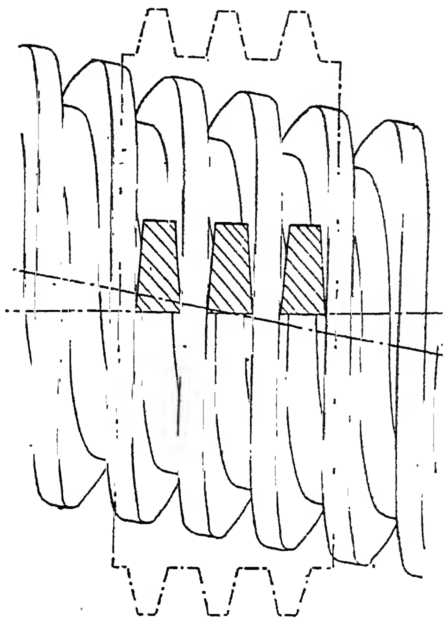


Fig. 20.—Showing centring of multiple-thread worm cutter.

Wheel Selection.—Thread grinding differs from ordinary operations on account of the delicacy of the wheel shapes, and a higher wheel speed may be necessary to put the grains into action more times and thus obtain the removal rate which is desired. But the necessity of maintaining a fine edge, such as a

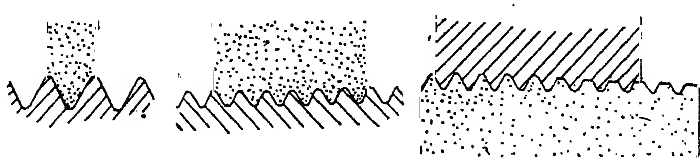


Fig. 21.—Single-rib, multi-rib, and taper wheels for thread grinding.

vee, renders it imperative to use an appropriately fine size of grain, as coarse particles will not true up to the state of finish demanded, and the kind of bond is also an important consideration. A vitrified bond is employed, resulting in a very rigid wheel which will not be deformed whilst being trued, nor deflect with side pressure such as might occur in correcting pre-cut threads containing lead errors.
Grit selection partly depends on the pitch of thread, but to certain extent

upon the skill of the workman and the condition of the diamonds, as well as the quality of finish required. An experienced man will be able to utilise a coarser wheel, setting it into the best state possible. The Norton Company recommend grit sizes from No. 120 to 150 for average use, but much finer are essential for fine pitches.

Coolants.—Special oils have been evolved, and the choice depends on the class of material. Soda-water suits for hard stock, and for high-speed steel (for taps and gauges) soluble oil and water is suitable. Potassium chromate is another selection. For soft and tough material a heavy oil may be applied.

Truing.—In order to keep a wheel in the free-cutting state the dulled grains must be dressed off at intervals, and the contour of the wheel also needs rectifi-

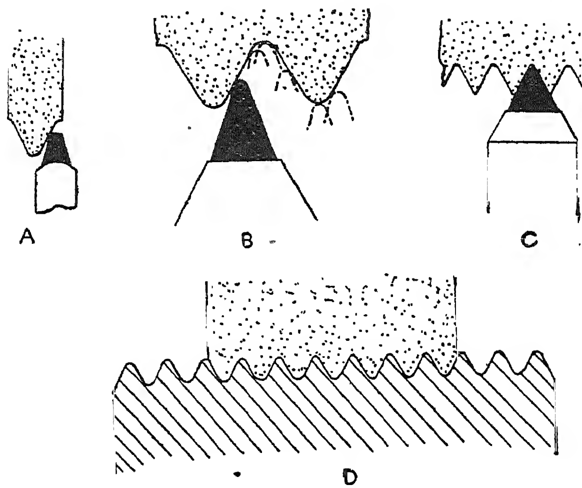


Fig. 22.—Methods of truing wheels by diamonds and by crusher roller.

cation, this being more particular for the finishing cut than the roughing one. Different types of dressing devices include a fixed-angle, standard style for American vee and pipe threads, various designs of pantograph mechanisms that obtain control from a greatly enlarged former and feed the diamonds to reproduce the profile on a reduced scale, cam and screw movement to generate multi-rib wheels, and crushers which impress their shape by force upon a multi-rib wheel already grooved by a diamond. The pantograph motion depends on the magnified former, filed or ground to the contour desired, but the stylus that travels around the former must have the same shape of corners as the diamond. In the Newall system a vertical projector apparatus is supplied for making the stylus from the diamond, reproducing the corners to the required magnification. The stylus also follows any inevitable inaccuracy in setting the diamond in its holder. No adjustment or focusing is necessary when projecting the diamond on to the stylus, the exact magnification and focus being given. A vice is attached to the table of the projector to facilitate filing the styli.

The wheel dresser on the Newall thread-grinding machines is either a single-rib or a multi-rib type, both dealing with shapes with angles not under 29 degrees. For lesser angles a worm dresser is furnished. Should the larger proportion of operations demand multi-rib wheels, the dresser of that kind is installed, and it

will also handle single-rib wheels. The diamonds are usually rectangular in form for the single rib, and chisel form for the multi-rib dresser. The diamond axis lies at an angle from that of the holder, in order to give front rake and permit of reversal when the first edge has worn. A ball-mounting on the holder causes the holder to tilt first to one side and then to the other, so as to impart side rake as it passes down the flanks of the grinding wheel.

Fig. 22 illustrates the three modes of dressing by diamond—A for single profiles, B the cam and screw control for multi-ribs, C the straight infeed of a shaped diamond to prepare the wheel for D, the steel roller crusher, should the threads have to be rounded. The crusher is either plain or serrated to prevent clogging. A simplified means of producing a grinder table by micrometer or other device is obtained in the Alfred Herbert " Annulix " arbor. This chucks the roller, which has had its groove roughed out, and moves it by automatic cam feed the distance of one pitch in the opposite direction from the table feed at each revolution of the arbor, more than one very light cut being taken over the series by a single-rib grinding wheel. As the arbor completes its revolution a gap between the grooves comes opposite the wheel, allowing of the lateral feed. A fresh cam is required for each pitch. A roll can be ground as many as forty-five times, and approximately will serve for twenty-five dressings on roughing, and eight or so for finishing operations. The scheme is also applicable to grinding thread hobs with annular threads, which are also backed off by the relieving mechanism of the machine.

Relieving and Other Mechanisms.—Relieving is either plain or accommodated to the spiral of a tap. In the Newall machines a sine-bar and rack-and-pinion action inparts a delayed or advanced movement to the hydraulic relief system in unison with the spiral, right- or left-hand.

Thread-matching devices are employed for setting a roughed-out piece in correct relation to the grinding-wheel. One type is built into a machine, another is a bench affair for setting the dog on the work before it goes to the machine.

To save time in grinding taps an arrangement can be fitted to cause a jump across the flutes at high speed, thereby avoiding the waste otherwise spent in waste motion.

Provision for grinding double, triple, quadruple, quintuple, or sextuple threads is incorporated in machines, using a graduated index-plate.

Thread Lapping.—It is sometimes necessary to lap a thread after grinding and the laps resemble those used for lapping of plug and ring gauges, but in this case the threads are cut in the working surface of the lap. The lap should not be made of a material harder than the screw thread it is desired to lap. Thread lapping should not be forced too hard into the work, and where the lapping is effected in a lathe the lathe spindle should be run with the back gears in. Frequent lap reversals are desirable, and the lap should be lightly charged with fine abrasive mixed with oil.

Laps are usually made of soft cast iron, copper, brass, or lead, but fine-grained cast iron is best. Copper does not finish the work so well as cast iron, but is sometimes advantageous when the first grinding in advance of lapping has not been too well done.

Thread Applications.—Whitworth screws or studs are generally used in soft metal on account of the deep thread afforded by the coarseness of the pitch. B.S.P. threads are used in connection with unions for petrol and oil piping. The nominal diameter of the thread refers to the bore of the piping for which it is suitable, and this practice is followed out in the case of union nuts, which are mostly tapped with this thread. Unions for both $\frac{1}{8}$-in. and $\frac{3}{16}$-in. diameter pipes are tapped $\frac{1}{8}$ B.S.P., although as a warning it should be mentioned that those for $\frac{3}{16}$-in. diameter are sometimes tapped $\frac{3}{8}$-in. diameter $\times$ 19 threads per inch.

B.A. threads are used in substitution for B.S.F. in sizes below $\frac{1}{4}$-in. diameter. These run from No. 0, just under $\frac{1}{4}$-in. diameter, to No. 22, about $\frac{1}{64}$-in. diameter, and are in common use on the items comprising instruments and electrical equipment. In this class of work, screws below No. 10 B.A. are seldom used, and therefore need not be considered.

Change Wheels and Lead Screws.—English lathes are supplied with a set of 22 change wheels rising by 5 teeth, the smallest having 15 or 20, and the largest 120 or 150. The set always includes either two 40-tooth gears, or two 60-tooth gears for cutting screws of the same pitch as the lead screw. Change wheels increase in size by 5 teeth from 15 teeth up to 100, and from 100 to 150 in regular increases of 10. Hence, pitches of lead screw and screw to be cut must be multiplied by 5, 10, 15, or 20 to obtain the number of teeth in drivers and driven gears respectively.

English lathes are usually fitted with a lead screw of 2 threads per inch, or $\frac{1}{2}$-in. pitch, but other lathes, particularly American, may have 4, 6, 8, or even 10 threads per inch in certain cases. In lathes having lead screws of 4, 6, or 8 threads per inch the change gears have teeth arranged in multiples of 4.

Direction of Saddle Movement.—If a right-handed screw is to be cut, the motion of the cutting tool is from the tailstock to the headstock, and the lead screw revolves in the same direction as the screw being cut. If the screw to be cut is of left-hand pitch the tool moves in the opposite direction and reverse motion is effected by using an additional intermediate wheel. An intermediate wheel is both a driver and a driven.

Simple Train.—A simple train consists of one driver placed on the lathe spindle, and one driven placed on the lead screw, any convenient gear being used to connect them.

Compound Train.—In a compound gear, four wheels are used, two being drivers and two being driven. Either of the drivers is fixed on the lathe spindle and gears with one of the driven, which is placed on one of the studs of the swing frame. The second driving wheel is fixed to the stud and gears with the remaining driven wheel, which is placed on the lead screw.

A compound train is used when the numbers representing the ratio of the leading screw and of the screw to be cut extend beyond the limits of an ordinary series of change wheels, or where a simple train would involve the use of gears too large to be accommodated on the swing train.

Ratio of Drivers to Driven.—The ratio of drivers to driven is equal to the ratio of the pitch of the lead screw to the pitch of the screw to be cut; therefore the number of teeth in the driver is determined by the pitch of the lead screw and the number of teeth in the driven wheel is calculated from the pitch of the screw to be cut.

In working change wheels express the ratio between the lead of the screw to be cut and the lead of the leading screw in the following manner:

$$\frac{\text{Lead of screw to be cut}}{\text{Lead of lead screw}} = \frac{\text{Drivers}}{\text{Driven}}.$$

The ratio can also be expressed in the following way:

$$\frac{\text{Threads per inch of the lead screw}}{\text{Threads per inch of required screw}} = \frac{\text{Drivers}}{\text{Driven}}.$$

The following examples will show how to calculate gear trains. For purpose of illustration it is assumed that the lead screw is of $\frac{1}{2}$-in. pitch or two threads per inch.

Find the ratio for a screw of $\frac{5}{8}$-in. lead:

$$\text{Ratio} = \frac{\frac{5}{8}}{\frac{1}{2}} = \frac{5}{8} \times \frac{2}{1} = \frac{10}{8} = \frac{5}{4}.$$

Find the ratio for a screw of $1\frac{1}{4}$-in. lead:

$$\text{Ratio} = \frac{1\frac{1}{4}}{\frac{1}{2}} = \frac{\frac{5}{4}}{\frac{1}{2}} = \frac{5}{4} \times \frac{2}{1} = \frac{10}{4} = \frac{5}{2}.$$

Find the ratio for a screw of $\frac{1}{4}$-in. lead :

$$\text{Ratio} = \frac{\frac{1}{4}}{\frac{1}{2}} = \frac{1}{4} \times \frac{2}{1} = \frac{2}{4} = \frac{1}{2}.$$

Find the ratio for a screw of $2\frac{1}{2}$-in. lead :

$$\text{Ratio} = \frac{2\frac{1}{2}}{\frac{1}{2}} = \frac{\frac{5}{2}}{\frac{1}{2}} = \frac{5}{2} \times \frac{2}{1} = \frac{10}{2} = \frac{5}{1}.$$

Calculating Simple Trains.—The following examples show how to calculate simple trains of gears on lathes having a lead screw of $\frac{1}{2}$ in. pitch.

Find the train of gears required to cut a screw of 5 threads per inch :

$$\text{Ratio} = \frac{2}{5}.$$

Multiply both terms of the fraction by 10. $\frac{2 \times 10}{5 \times 10} = \frac{20}{50}$. The gears are thus 20 and 50.

What are the gears required to cut a thread of $\frac{3}{8}$-in. pitch ?

$$\text{Ratio} = \frac{\frac{3}{8}}{\frac{1}{2}} = \frac{3}{8} \times \frac{2}{1} = \frac{6}{8} = \frac{3}{4}.$$

Multiply numerator and denominator by 15 :

$$\frac{3}{4} \times \frac{15}{15} = \frac{45}{60}.$$

The gears are thus 45 and 60, the 45 being the driver and the 60 the driven.

What are the gears required to cut a thread of 6 threads per inch ?

$$\text{Ratio} = \frac{2}{6}.$$

Multiply numerator and denominator by 10 :

$$\frac{2}{6} \times \frac{10}{10} = \frac{20}{60},\ \text{the necessary gears.}$$

In simple trains the distance between driver and driven may be made up by two intermediate gears having equal number of teeth or by any simple wheel that will properly mix.

Calculating Compound Trains.—It is usually necessary to employ compound trains for cutting screws with more than 12 threads per inch and for screws having a lead of more than $\frac{1}{2}$ in.

Example.—What gears are required to cut 24 threads per inch ?

$$\text{Ratio} = \frac{2}{24}.$$

As the smallest gear is usually 20, this would mean that for a simple train gears of 20 and 240 teeth would be required. Proceed as follows :

$$\frac{20}{240} = \frac{2 \times 10}{6 \times 40}.$$

In other words, the numerator and the denominator have been split up into their fractions.

Now multiply numerator and denominator of $\frac{2}{6} \times 10$, obtaining $\frac{20}{60}$. Multiply numerator and denominator of $\frac{10}{40} \times 3$, obtaining $\frac{30}{120}$.

The change gears, therefore, required to cut 24 threads per inch are:

$$\frac{\text{Drivers } 20 \times 30}{\text{Driven } 60 \times 120}.$$

The 20 gear is the first driving wheel, the 60 wheel is a driven wheel on the quadrant stud, the 30 wheel is a driver wheel on the quadrant stud, and 120 wheel is fixed on the lead screw.

Find the change gears required to cut 27 threads per inch on a lead screw having 6 threads per inch. On such a lathe the change wheels would be arranged in multiples of 4:

$$\text{Ratio} = \frac{6}{27} = \frac{2}{9} = \frac{2 \times 1}{3 \times 3}.$$

Multiply numerator and denominator of $\frac{2}{3} \times 12$, obtaining $\frac{24}{36}$. These are the first driver and first driven gears. Multiply both terms of the second fraction by 20, obtaining $\frac{20}{60}$. These are the remaining gears. The 24 gear is placed on the mandrel and is the driver.

Compound trains of wheels for cutting worms of the following pitches, 1 in., $1\frac{1}{16}$ in., $1\frac{1}{8}$ in., and $1\frac{1}{2}$ in.-pitch worms, where the lead screw has two threads, or $\frac{1}{2}$ in. pitch, and wheel on mandrel constant at 40 teeth will be as follows, their ratios being respectively: $\frac{2}{1}, \frac{17}{8}, \frac{9}{4}$, and $\frac{3}{1}$. Thus 1-in. pitch may be cut by 40 on the spindle gearing to any wheel gearing to 60, and on the 60 spindle a 150 gearing to 50 on the screw, or 40 driver, 40 follower, 100 driver, and 50 follower on screw will give the same result; also 40, 60, 120, 40, and many others. There are not so many combinations for the $1\frac{1}{16}$-in. and $1\frac{1}{8}$-in. pitches, but there are several for the $1\frac{1}{2}$-in. pitch.

Compound trains of wheels become necessary when the difference between driver and driven is too great for a simple train. Thus:

$$\frac{\text{Pitch of screw to be cut}}{\text{Pitch of guide screw}} = \frac{\text{Number of teeth in first driver}}{\text{Number of teeth in first follower}} \cdot \frac{\text{Number of teeth in second driver}}{\text{Number of teeth in second follower}}.$$

Given a screw to be cut 20 per inch, or $\frac{1}{20}$ pitch, then arranged as above:

$$\frac{\frac{1}{20}}{\frac{1}{2}} = \frac{1}{10} = \frac{1}{4} \times \frac{1}{2\frac{1}{2}} = \text{wheels of } \frac{20}{80} \times \frac{40}{100}.$$

Thus $\frac{20}{80} \times \frac{40}{100} = \frac{800}{8000}$ or $\frac{8}{80}$ or $\frac{1}{10}$, same as the original ratio of work, going one revolution while the lead screw goes 10 revolutions in the same time. Another train for a coarse pitch, as in a double or treble thread of $2\frac{1}{2}$-in. pitch from thread to thread, would be arranged as follows: $\frac{2\frac{1}{2}}{\frac{1}{2}} = \frac{5}{1}$ the $\frac{2 \times 2\frac{1}{2}}{1 \times 1}$ makes wheels of $\frac{60}{30} \times \frac{50}{20}$; $60 \times 50 = 3000$, and $30 \times 20 = 600$; the ratio is $\frac{3000}{600}$ or $\frac{30}{6}$ or $\frac{5}{1}$, thus coming back to the original fraction $\frac{5}{1}$. It will be noticed in the above examples that the fractions $\frac{1}{10}$ and $\frac{1}{5}$ are split up into factors to get a compound quantity

for a compound train. Thus $\frac{1}{10}$ is a quantity, but $\frac{1}{4} \times \frac{1}{2\frac{1}{2}}$ is $\frac{1}{10}$ in value, because 1×1 of the top line = 1, and $4 \times 2\frac{1}{2}$ of the bottom line = 10 : thus it becomes $\frac{1}{10}$ again, or vice versa; but having got these factors of $\frac{1}{10}$ ratio, namely $\frac{1}{4}$ and $\frac{1}{2\frac{1}{2}}$, these multiplied become $\frac{1}{4} \times \frac{2}{5}$. Then to get wheels of the same value, multiply all these figures by the same number. A convenient one may be 15 or 20. Taking 20, the train becomes $20 \times 1 = 20$, and $20 \times 2 = 40$; $20 \times 4 = 80$; and $20 \times 5 = 100$. Thus the train is $\frac{20 \times 40}{80 \times 100}$.

Proving Change Wheels.—It is always wise to prove a train of change wheels before commencing to cut. This should be done by reversing the process given, multiplying the drivers together, and dividing the answer by the driven gears multiplied together. The answer multiplied by the lead or pitch of the lead screw equals the lead of screw to be cut.

Cutting Number of Threads in a Given Length.—Assume that it is required to cut 6 threads in $1\frac{1}{8}$ in. A pitch of 6 in $1\frac{1}{8}$ in. is the same as 48 threads in 9 in. This conversion is the first step—multiply the thread by the least number which will make it a whole number; in this case $1\frac{1}{8}$ has been multiplied by 8 = 9 in. Similarly, multiply the number of threads in $1\frac{1}{8}$ in. by 8 = 48. In 9 in. of lead screw there are 18 threads (2 threads per inch). Therefore the ratio between lead screw and screw to be cut is:

$$\frac{18}{48} = \frac{3}{8}. \text{ Then gears } \frac{30}{80}, \text{ or } \frac{45}{120}, \text{ will cut 6 threads in } 1\tfrac{1}{8} \text{ in.}$$

Prime Number Threads.—Any prime number of threads per inch can be cut with leading screws of 2 or 4 threads per inch, but not with a leading screw of 3 t.p.i. without nullifying the prime numbers, which are not multiples of 3 with a wheel based on them.

Cutting Multiple Threads.—In cutting multiple-threaded screws, worms, or even hobs, the turner is usually relied on to make provision for the division of the blank to locate the positions of the starts. If a double thread (sometimes called a "double-start" thread) is being cut after the first thread has been cut, the change gear is divided and the two teeth marked with chalk. The tooth space, into which the gear enters, is also marked. The swing frame is then lowered, and the lathe spindle turned round until the next marked tooth is coincident with the chalked space of the gear that meshes with it. It is thus certain that the carriage and screw-cutting tool are in the correct position for cutting the next thread.

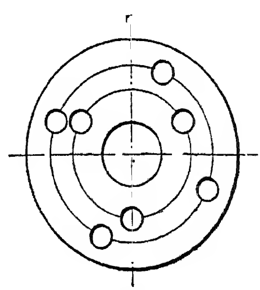


Fig. 23.—Faceplate for cutting multi-start threads.

First one thread is cut in the usual manner until the uncut material between the grooves is equal to the width of the thread already cut. The change gears are then disengaged, and the lathe spindle, along with the work, is given half a turn. The gears are then intermeshed and the second thread cut. When cutting triple threads, the work is given a third of a revolution, and in the case of quadruple threads a quarter of a revolution.

Fig. 23 is a face view of a faceplate that may be used for multiple screw-cutting. It is $4\frac{1}{2}$ in. in diameter and $\frac{1}{2}$ in. thick, bored and threaded to fit the lathe mandrel; it is faced true in position. Two circles are marked on the face with a vee tool, as shown in Fig. 23. The large circle ($3\frac{1}{2}$ in.) is carefully divided into four and centre-punched. The small circle ($2\frac{1}{2}$ in.) is divided into three and centre-punched. Holes are drilled through with a $\frac{7}{16}$-in. drill.

For use in cutting a double thread, the stud is fixed in one of the outer holes, and one thread in the usual manner with the carrier driven by the stud. The stud is then moved to the opposite hole and the other thread finished. In cutting a triple thread, each of the threads is cut separately by fixing the stud in one of the inner holes in the faceplate and then moving the stud to the second and third hole as required. For cutting a quadruple thread, each of the four outer holes is used in turn. Use a tool slightly narrower than the finished size, and cut down to the required depth all the threads, then finish with a freshly ground tool to the finished size.

Picking-up Threads.—When cutting threads whose pitch is not an aliquot part of the lead screw, it is necessary to have some method of "picking-up" or catching the thread should it be necessary to take more than one cut. If the lead screw is 2 t.p.i., the clasp nut can be thrown in at any portion of the traverse for either 2, 4, 6, 8, 10, 12, 14, 16, etc. Hence, when the number of threads to be cut can be divided by the number of threads per inch of the lead screw without a remainder, the clasp nut will engage at any portion of the lead screw.

In cutting a number of threads per inch which cannot be so divided, the least common multiple of the pitches concerned is found. As an example, assume that a thread of $\frac{5}{8}$-in. pitch is to be cut on a lead screw of 2 t.p.i. In this case there are $1\frac{3}{5}$ t.p.i. The pitch of the lead screw is $\frac{1}{2}$ in.; therefore, multiplying the numerators together, $\frac{5}{8}$ and $\frac{4}{8}$, the minimum length in which there will be a complete number of threads in both lead screw and thread to be cut, will be

$$\frac{5 \times 4}{8} = 2\tfrac{1}{2} \text{ in.}$$

The clasp nut may be thrown in gear at $2\frac{1}{2}$ in., 5 in., $7\frac{1}{2}$ in., and so on. In the case of a $\frac{5}{8}$-in.-pitch screw shorter than the minimum of $2\frac{1}{2}$ in., the carriage must be traversed back $2\frac{1}{2}$ in. Should it be $4\frac{1}{2}$ in. long, traverse the carriage back 5 in.

It is customary in many workshops to run the saddle back to the movable headstock, and then to make a mark on the lead screw. A suitable mark is similarly made on the faceplate.

In picking-up the thread for a second or third cut, as the case may be, the saddle is run back to the headstock, and the lathe is then permitted to run until the marks on the leading screw and the faceplate come to their relative positions. The clasp nut is then thrown in.

Threading Close to a Shoulder.—The following formula can be used to determine how close to a shoulder a full thread can be cut on the work:

$$D = F \times P$$

where:

D = the required minimum distance of the full thread from the shoulder.
F = 1·757 for Whitworth form.
1·784 for U.S.S. form.
1·648 for B.A. form.
2·379 for 60-degree Sharp V form.
1·933 for S.I. form.
P = Pitch of thread in fractions of an inch or in millimetres.

D will be in fractions of an inch for the first four standards and in millimetres for the Système Internationale (S.I.).

D is the net theoretical distance, and enough should be added in practice to ensure that the dies do not come in contact with the shoulder (say, 0·015 or 0·3 mm.).

CHANGE-WHEELS

Two alternative trains are given

Threads per Inch to be Cut	*Lead Screw, ¼-in. Pitch*				*Lead Screw, ½-in. Pitch*			
	Drivers		*Driven*		*Drivers*		*Driven*	
50	20	30	75	100	20	20	100	100
	20	40	80	125	20	30	120	125
48	20	25	60	100	20	25	100	120
	25	30	75	120	20	20	80	120
45	20	30	75	90	20	20	75	120
	20	40	90	100	20	25	90	125
40	20	55	100	110	20	30	100	120
	20	40	80	100	20	25	100	100
35	30	40	100	105	20	30	100	105
	20	40	70	100	25	30	105	125
30	20	60	90	100	20	40	100	120
	20	50	75	100	20	35	100	105
28	20	30	40	105	20	25	70	100
	20	30	60	70	20	45	105	120
26	20	30	60	65	20	25	65	100
	25	40	65	100	20	30	65	120
25	30	40	75	100	20	30	75	100
	20	60	75	100	20	60	120	125
24	20		120		25	30	75	120
	20	40	60	80	20	25	60	100
23	20		115		20	50	100	115
	30	40	60	115	20	30	60	115
22	20		110		20	30	60	110
	30	50	76	115	20	40	80	110
21	20	40	60	70	20	40	70	120
	30	40	70	90	20	30	70	90
20	20		100		20	40	80	100
	20	40	50	80	20	35	70	100
19	20		95		25	40	95	100
	30	40	60	95	20	60	95	120
18	20		90		25	40	75	120
	30	40	60	90	35	40	105	120

CHANGE WHEELS—*continued*

Threads per Inch to be Cut	*Lead Screw, ¼-in. Pitch*		*Lead Screw, ½-in. Pitch*	
	Drivers	*Driven*	*Drivers*	*Driven*
17	20 30 40	85 60 85	20 60 20 45	85 120 85 90
16	20 35 40	80 70 80	25 30 30 45	50 120 90 120
15	20 20 40	75 30 100	20 80 20 70	100 120 100 105
14	20 30 40	70 60 70	20 75 20 50	100 105 70 100
13	20 40 45	65 65 90	20 50 20 60	65 100 65 120
12	20 30 50	60 60 75	20 25 60	120 90 100
11	40 30 40	110 55 60	20 30 60	110 90 110
10	40 30 40	100 50 60	20 35 60	100 100 105
9	40 30 40	90 45 60	20 30 70	90 90 105
8	40 20 75	80 50 60	20 35 60	80 70 120
7½	40 20 80	75 50 60	20 30 80	75 75 120
7	40 30 80	70 60 70	20 30 80	70 70 120
6½	40 30 60	65 45 65	20 30 80	65 65 120
6	30 20 60	45 40 45	30 35 80	90 70 120
5½	40 40 60	55 30 110	20 40	55 110
5	40 60	50 75	30 40	75 100

CHANGE WHEELS—*continued*

Threads per Inch to be Cut	*Lead Screw, ¼-in. Pitch*		*Lead Screw, ½-in. Pitch*	
	Drivers	*Driven*	*Drivers*	*Driven*
4½	40 40 100	45 75 60	40 20	90 45
4	40 30 105	40 90 35	30 40	60 80
3½	40 40 60	35 30 70	40 30 90	70 45 105
3¼	80 70 40	65 35 65	40 50 80	65 65 100
3	80 40	60 30	40 30	60 45
2⅞	40 100 40 120	115 25 115 30	20 100 40 100	115 25 115 50
2¾	80 60 100	55 55 75	40 80	55 110
2⅝	40 100 40 120	105 25 105 30	80 40 110	105 105 50
2½	80 40 80	50 75 30	40 40 120	50 100 60
2⅜	40 100 40 120	95 25 95 30	80 40 100	95 95 50
2¼	80 40 100	45 75 30	40 40 100	45 90 50
2	80 40 75	40 50 30	60 30 75	60 90 25
1⅞	40 80 40 80	50 30 75 20	80 40 80	75 100 30
1¾	80 80 100	35 70 50	80 60 90	70 105 45
1⅝	60 80 50 80	65 30 55 25	60 100 40 90	75 65 65 45
1½	80 60 100	30 75 30	80 60 110	60 90 55

CHANGE WHEELS—*continued*

Threads per Inch to be Cut	*Lead Screw, $\frac{1}{4}$-in. Pitch*				*Lead Screw, $\frac{1}{2}$-in. Pitch*			
	Drivers		*Driven*		*Drivers*		*Driven*	
$1\frac{3}{8}$	80	120	110	30	80		55	
	80	50	55	35	80	70	110	35
$1\frac{1}{4}$	80		25		80		50	
	80	120	75	40	40	120	100	30
$1\frac{1}{8}$	60	80	45	30	80		45	
	80	100	50	45	80	100	90	50
1	100		25		60		30	
	80	100	50	40	80		40	
One Thread in $1\frac{1}{4}$ in.	100	120	60	40	100		40	
	75	50	30	25	80	75	60	40
$1\frac{1}{2}$ in.	80	90	40	30	90		30	
	70	75	35	25	60	70	40	35
$1\frac{3}{4}$ in.	70	75	30	25	75	105	90	25
	80	105	40	30	70	105	60	35
2 in.	80	100	40	25	80	60	40	30
	75	80	30	25	70	110	55	35
$2\frac{1}{4}$ in.	75	90	30	25	90	105	60	35
	90	100	40	25	70	90	40	35
$2\frac{1}{2}$ in.	100	75	30	25	75	100	50	30
	100	120	40	30	75	110	55	30
$2\frac{3}{4}$ in.	100	110	40	25	100	110	50	40
	110	75	30	25	90	110	45	40
3 in.	90	110	30	25	90	100	50	30
	105	120	35	30	75	150	50	25

A full set of change wheels usually consists of 22 wheels, ranging from 20 teeth to 120 teeth, progressing in fives. One of the smaller gears, usually a 40, is in duplicate.

OPTICAL AND GAUGE BLOCKS

The following table gives the measuring ranges and orders of accuracy of optical and gauge-block systems of measurement.

Instrument	*Capacity*	*Measuring Range*	*Value of Scale Division*	*Order of Accuracy*
Optical protractor	360°	360°	360 secs.	300 secs.
Autocollimator	1°	1°	30 secs.	6 secs.
Zeiss graduated circle	360°	360°	60 secs.	20 secs.
Zeiss angular division tester	360°	360°	1 sec.	2 secs.
Angle gauge blocks	90°	90°	1·5 sec.	1 sec.

CHANGE WHEELS FOR MILLIMETRIC PITCHES

Pitch of Screw to be Cut	*Lead Screw, ¼-in. Pitch*		*Lead Screw, ½-in. Pitch*	
Millimetres	*Drivers*	*Driven*	*Drivers*	*Driven*
1 (0·039 in.)	63 × 20 35 × 45	80 × 100 100 × 100	21 × 30 21 × 45	80 × 100 100 × 120
2 (0·079 in.)	63 × 30 63 × 40	60 × 100 80 × 100	63 × 20 63 × 30	80 × 100 100 × 120
3 (0·118 in.)	63 × 30 63 × 45	40 × 100 60 × 100	63 × 30 63 × 45	80 × 100 100 × 120
4 (0·157 in.)	63 × 30 63 × 20	50 × 60 40 × 50	63 × 30 63 × 20	60 × 100 50 × 80
5 (0·197 in.)	63 × 30 45 × 70	40 × 60 50 × 80	63 × 30 45 × 70	60 × 80 80 × 100
6 (0·236 in.)	63 × 45 63 × 60	50 × 60 50 × 80	63 × 30 63 × 45	50 × 80 60 × 100
7 (0·275 in.)	63 × 35 63 × 70	40 × 50 50 × 80	63 × 35 63 × 70	50 × 80 80 × 100
8 (0·315 in.)	63 63 × 45	50 50 × 70	63 63 × 45	100 60 × 75
9 (0·354 in.)	63 × 90 63 × 45	50 × 80 40 × 50	63 × 45 63 × 90	50 × 80 80 × 100
10 (0·393 in.)	63 70 × 90	40 50 × 80	63 70 × 90	80 80 × 100
11 (0·433 in.)	63 × 55 63 × 110	25 × 80 50 × 80	63 × 55 63 × 110	50 × 80 80 × 100
12 (0·474 in.)	63 × 30 63 × 60	20 × 50 40 × 50	63 × 30 63 × 60	40 × 50 50 × 80
13 (0·512 in.)	63 × 65 63 × 65	40 × 50 25 × 80	63 × 65 63 × 65	40 × 100 50 × 80
14 (0·551 in.)	63 × 70 63 × 105	40 × 50 40 × 75	63 × 70 63 × 70	50 × 80 40 × 100
15 (0·591 in.)	63 × 75 63 × 90	40 × 50 40 × 60	63 × 75 63 × 90	50 × 80 60 × 80
16 (0·630 in.)	63 × 80 63 × 60	40 × 50 30 × 50	63 × 80 63 × 60	50 × 80 50 × 60
17 (0·669 in.)	63 × 85 63 × 85	20 × 100 40 × 50	63 × 85 63 × 85	40 × 100 50 × 80
18 (0·708 in.)	63 × 90 63 × 45	40 × 50 20 × 50	63 × 90 63 × 45	50 × 80 40 × 50
19 (0·748 in.)	63 × 95 63 × 95	40 × 50 20 × 100	63 × 95 63 × 95	50 × 80 40 × 100

CHANGE WHEELS FOR MILLIMETRIC PITCHES—*continued*

Pitch of Screw to be Cut	*Lead Screw, ¼-in. Pitch*		*Lead Screw, ½-in. Pitch*	
Millimetres	*Drivers*	*Driven*	*Drivers*	*Driven*
20 (0·787 in.)	63 × 75 63 × 60	25 × 60 30 × 40	63 × 75 63 × 60	50 × 60 40 × 60
21 (0·826 in.)	63 × 63 63 × 63	20 × 60 30 × 40	63 × 63 63 × 63	40 × 60 30 × 80
22 (0·866 in.)	63 × 55 63 × 100	20 × 50 40 × 50	63 × 55 63 × 100	40 × 50 50 × 80
23 (0·905 in.)	63 × 46 63 × 115	20 × 40 40 × 50	63 × 46 63 × 115	40 × 40 50 × 80
24 (0·945 in.)	63 × 90 63 × 60	30 × 50 20 × 50	63 × 90 63 × 60	50 × 60 40 × 50
25 (0·984 in.)	63 × 50 70 × 90	20 × 40 40 × 40	63 × 50 70 × 90	20 × 80 40 × 80
26 (1·023 in.)	63 × 65 63 × 65	20 × 50 25 × 40	63 × 65 63 × 65	25 × 80 40 × 50
27 (1·063 in.)	63 × 54 63 × 81	20 × 40 30 × 40	63 × 54 63 × 81	20 × 80 40 × 60
28 (1·102 in.)	63 × 70 63 × 70	20 × 50 25 × 40	63 × 70 63 × 70	40 × 50 25 × 80
29 (1·140 in.)	63 × 58 63 × 145	20 × 40 20 × 100	63 × 58 63 × 145	20 × 80 40 × 100
30 (1·180 in.)	63 × 60 63 × 90	20 × 40 30 × 40	63 × 60 63 × 90	20 × 80 40 × 60
31 (1·220 in.)	63 × 62 63 × 62	20 × 40 25 × 32	62 × 62 63 × 62	20 × 80 40 × 40
32 (1·260 in.)	63 × 60 63 × 80	25 × 30 25 × 40	63 × 60 63 × 80	30 × 50 40 × 50
33 (1·300 in.)	33 × 63 66 × 63	20 × 20 20 × 40	66 × 63 63 × 99	20 × 80 40 × 60
34 (1·338 in.)	63 × 85 63 × 85	20 × 50 25 × 40	63 × 85 63 × 85	40 × 50 25 × 80
35 (1·378 in.)	63 × 70 63 × 105	20 × 40 30 × 40	63 × 70 63 × 70	40 × 40 20 × 80
36 (1·417 in.)	63 × 90 63 × 90	20 × 50 25 × 40	63 × 90 63 × 90	40 × 50 25 × 80
37 (1·456 in.)	63 × 37 63 × 74	20 × 20 20 × 40	63 × 37 63 × 74	20 × 40 20 × 80
38 (1·496 in.)	63 × 95 63 × 95	25 × 40 20 × 50	63 × 95 63 × 95	40 × 50 20 × 100

CHANGE WHEELS FOR MILLIMETRIC PITCHES—*continued*

Pitch of Screw to be Cut	*Lead Screw, ¼-in. Pitch*		*Lead Screw, ½-in. Pitch*	
Millimetres	*Drivers*	*Driven*	*Drivers*	*Driven*
39 (1·535 in.)	63 × 78	20 × 40	63 × 78	40 × 40
	63 × 78	25 × 32	63 × 78	20 × 80
40 (1·575 in.)	63 × 80	20 × 40	63 × 80	40 × 40
	63 × 40	20 × 20	70 × 90	40 × 50
42 (1·653 in.)	63 × 84	20 × 40	63 × 105	40 × 50
	63 × 105	20 × 40	63 × 81	20 × 80
44 (1·732 in.)	63 × 55	20 × 25	63 × 55	20 × 50
	63 × 110	25 × 40	63 × 110	40 × 50
45 (1·770 in.)	63 × 45	20 × 20	63 × 45	20 × 40
	63 × 90	20 × 40	63 × 90	40 × 40
46 (1·811 in.)	63 × 115	20 × 50	63 × 115	40 × 50
	63 × 115	25 × 40	63 × 115	20 × 100
48 (1·890 in.)	63 × 60	20 × 25	63 × 60	25 × 40
	63 × 90	25 × 30	63 × 90	30 × 50
50 (1·968 in.)	63 × 50	20 × 20	63 × 50	20 × 40
	63 × 75	20 × 30	63 × 75	30 × 40
55 (2·165 in.)	63 × 55	20 × 20	63 × 55	20 × 40
	63 × 110	20 × 40	63 × 110	40 × 40
60 (2·362 in.)	63 × 60	20 × 20	63 × 60	20 × 40
	63 × 90	20 × 30	63 × 75	20 × 50
65 (2·560 in.)	63 × 65	20 × 20	63 × 65	20 × 40
	63 × 78	20 × 24	63 × 78	20 × 48
70 (2·756 in.)	63 × 70	20 × 20	63 × 70	20 × 40
	63 × 105	20 × 30	63 × 105	20 × 60
75 (2·953 in.)	63 × 75	20 × 20	63 × 75	20 × 40
	63 × 90	20 × 24	63 × 90	20 × 48
80 (3·149 in.)	63 × 80	20 × 20	63 × 80	20 × 40
	63 × 100	20 × 25	63 × 100	25 × 40
85 (3·346 in.)	63 × 85	20 × 20	63 × 85	20 × 40
	63 × 102	20 × 24	63 × 102	24 × 40
90 (3·543 in.)	63 × 90	20 × 20	63 × 90	20 × 40
	63 × 108	20 × 24	63 × 108	40 × 24
95 (3·740 in.)	63 × 95	20 × 20	63 × 95	20 × 40
	63 × 76	20 × 16	63 × 76	20 × 32
100 (3·930 in.)	63 × 100	20 × 20	63 × 100	20 × 40
	70 × 90	20 × 20	70 × 90	20 × 40

CHANGE GEARS FOR SCREW CUTTING

(Other ratios given on pages 557 to 563)

FIRST TWO NUMBERS REPRESENT TEETH IN "DRIVING" GEARS
SECOND TWO NUMBERS REPRESENT TEETH IN "DRIVEN" GEARS

Number of Threads to be Cut per Inch	NUMBER OF THREADS PER INCH IN LEAD SCREW																			
	2				4				6				8				10			
1	75	40	50	30	75	40	25	30	75	60	25	30	75	80	25	30	90	100	20	45
1½	75	40	50	45	75	40	25	45	75	60	25	45	75	80	25	45	90	100	30	45
2	75	40	50	60	75	40	50	30	75	60	50	30	80	60	40	30	90	100	40	45
2½	40	60	60	50	40	60	50	30	60	50	50	25	80	60	50	30	90	100	50	45
3	80	25	60	50	50	40	25	60	75	40	50	30	80	50	25	60	80	50	60	30
3½	30	60	45	70	100	60	75	70	75	80	50	70	80	50	25	70	80	50	70	30
4	50	60	75	80	75	40	50	60	90	50	75	40	75	40	50	30	90	50	40	45
5	40	30	60	50	80	45	90	50	45	40	30	50	100	60	75	50	75	40	50	30
6	25	40	50	60	80	25	60	50	75	40	50	60	50	40	25	60	100	60	80	45
7	30	40	60	70	30	60	45	70	45	80	60	70	100	60	75	70	75	80	60	70
8	30	40	60	80	50	60	75	80	30	75	50	60	75	40	50	60	50	45	45	40
9	40	50	100	90	80	50	100	90	45	80	60	90	80	70	70	90	100	40	40	90
10	30	60	90	100	50	60	75	100	50	90	75	100	40	70	70	50	75	40	50	60
11	25	30	75	55	25	60	75	55	50	45	75	55	60	50	75	55	50	60	60	55
12	25	40	75	80	50	40	75	80	50	60	75	80	80	25	60	50	50	40	30	80
14	30	25	75	70	30	40	60	70	45	40	60	70	50	60	75	70	75	40	60	70

CHANGE GEARS FOR SCREW CUTTING *continued*

FIRST TWO NUMBERS REPRESENT TEETH IN "DRIVING" GEARS
SECOND TWO NUMBERS REPRESENT TEETH IN "DRIVEN" GEARS

Number of Threads to be Cut per Inch	Number of Threads per Inch in Lead Screw																			
	2				4				6				8				10			
16	30	25	75	80	50	30	75	80	30	75	100	60	50	60	75	80	50	45	45	80
18	40	25	100	90	40	50	100	90	45	40	60	90	40	70	70	90	50	40	40	90
20	25	30	75	100	25	60	75	100	25	90	75	100	40	70	70	100	50	60	60	55
22	25	20	55	100	25	30	.75	55	25	45	75	55	30	50	75	55	50	30	60	55
24	30	25	90	100	25	40	75	80	25	60	75	80	40	25	60	50	50	40	60	80
26	20	25	100	65	25	30	75	65	25	45	75	65	30	50	75	65	30	50	60	65
28	20	25	100	70	25	30	75	70	30	40	80	70	30	40	60	70	50	40	80	70
30	20	25	100	75	40	30	100	90	50	30	75	100	30	40	60	75	25	40	50	60
32	20	25	100	80	25	30	75	80	25	30	50	80	25	60	75	80	25	45	45	80
35	15	20	70	75	20	30	70	75	20	30	50	70	30	40	70	75	30	50	75	70
36	20	25	100	90	40	25	100	90	25	40	75	80	40	50	100	90	30	50	60	90
40	15	30	90	100	25	30	75	100	25	45	75	100	30	60	90	100	30	40	60	80
44	25	20	110	100	25	20	55	100	25	30	55	100	25	30	55	75	25	40	55	80
45	15	20	75	90	30	20	75	90	30	40	90	100	30	40	75	90	30	50	75	90
48	15	25	90	100	30	25	90	100	25	30	75	80	25	40	75	80	25	50	75	80
50	15	20	75	100	30	20	75	100	20	30	50	100	30	40	75	100	30	60	90	100

MACHINE TAPS AND DIES

The use of taps and dies in various machines differs from hand control in several ways. There is the correct alignment which is ensured by the mode of holding, and release or reversal is quickly obtained. For very accurate cutting it is sometimes the practice to give lead-screw motion, which also eases the taps and dies, and is better in certain materials. Duplex threads at different spots are accurately pitched by the same device. Different kinds of taps and dies are employed for many machine equipments, with more leads, and adjustment methods which scarcely apply to hand-actuated tools, while pilotage is common, especially for fine shallow threads. Flat taps serve well for some classes of operations, being fitted with pilots. Inserted chaser-taps and dies are extensively used, also adjustable types, and collapsing taps and opening dies occur in a great number of set-ups.

Floating Action.—As with other forms of tool which follow on a primary cut, taps and dies may possess floating action. Relief by recessing the end of a hole

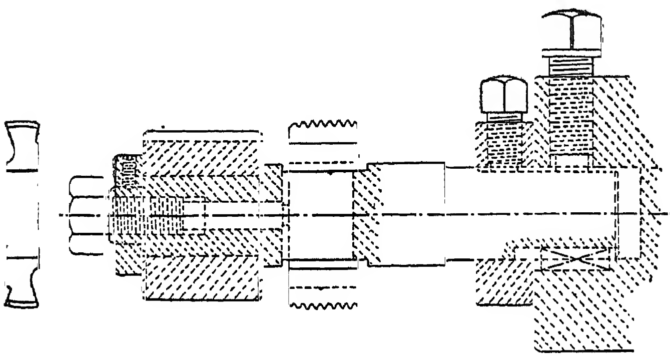


Fig. 24.—Flat blade tap with pilot.

or necking a turned part is usual in order to let a tap or die clear easily, but sometimes such treatment is unnecessary, or a piece will require to have a radiused union with a shoulder for strength. Particular types of taps and dies are made for use in certain machines, specifically the bolt and other screwing machines, and tapping machines including automatics. We shall consider first the applications of ordinary and special kinds in capstan, turret, and auto-turning lathes, automatic screw machines, boring mills, and related machines.

Taps for Turret Work.—Ordinary hand taps can be held in turret holders, or cylindrical-shank taps are gripped by a set-screw socket. Generally the holder takes a firm bite or has a friction grip, but a sensitive holder is supplied with head free to revolve, until clasped with the hand on the knurled body. This affords delicate control for small taps. The shank is graduated to indicate the depth tapped. More than four lands often occur in the larger taps, and some form of guidance is often essential, either by a reamer end or a plain pilot, which may be attached by a spigot and nut. Shallow threads would otherwise be liable to come thin at one side, especially in soft material. A shell tap is sometimes employed on a piloted bar, or a flat chaser can be secured instead. One of the difficulties of tapping is that of clogging behind the cutting edges when the reverse is put in,

and two-edged styles are often selected to reduce the trouble. The pilot end is either solid or provided with a loose bush, as given in Fig. 24 (Alfred Herbert), fluted for flow of coolant. The stem is held by the key and set-screw after setting the longitudinal position by the collar.

Adjustable Taps.—For sizing purposes taps can be made adjustable by a split body and taper bolt, or by packing out blades with shims, afterwards locking the blades in their slots by wedges. A convenient system is embodied in the geometric tap (Fig. 25), the body of which serves for a number of different-size

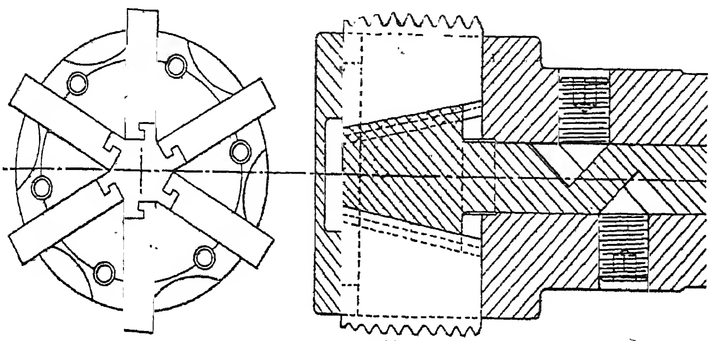


Fig. 25.—The geometric adjustable tap.

chasers, which are easily removed for sharpening. The cap only overhangs the chasers slightly, but for tapping down to the end of a blind hole a special bottoming cap may be substituted. The chasers engage by hooks to the plunger and draw inwards or outwards when the latter is moved by loosening one adjusting screw and tightening the other. The range of capacities extends in the smallest tool from $1\frac{5}{16}$ in. to $1\frac{5}{8}$ in., and in the largest from $6\frac{1}{2}$ in. to $8\frac{1}{2}$ in.

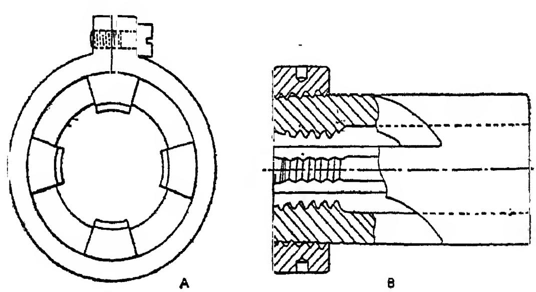


Fig. 26.—Adjustable tap in which different-size chasers can be placed.

Dies.—The round or bottom die is extensively favoured for capstan and screw-machine work of small and medium size. For larger dimensions the number of lands is increased, and particularly for brasswork such dies are freely employed. For the ferrous materials and other harder kinds the opening die-heads come into use. Spring or prong dies are handy for small work, afford plenty of chip clearance, and may be set to fine limits. Moreover, sharpening is easy. Four

prongs are usual or six for bigger styles, and regulation depends on the contraction of a split collar (Fig. 26A), or one threaded over (B), providing uniform movement of each land. The knurled collar has a taper thread (exaggerated in the view) so that the point of the die is contracted most, and there is no tearing when backing off, and the correct amount of clearances is obtained. A four-prong die is made which has a taper nose ground concentric with the thread, and a cap is screwed along the body of the holder to effect closing. The cap has large side openings for chip flow. Individual screw-setting is done for large dies as an alternative to a ring. But the idea is more cumbersome and requires care to get concentricity.

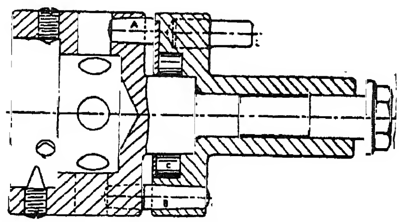


Fig. 27.—Taylor self-releasing die-holder.

A die which furnishes the same need as the tap in Fig. 25 gives features of compactness, adjustment for sizing, and facile chaser removal for grinding. The outfit (Fig. 29) carries four chasers in a skeleton which holds them by keys, and cams effect the positions, as the one adjusting screw is slackened and the other tightened. The rims of body and skeleton are graduated for observing the amount of alteration.

Die-holders.—The stemmed holder necessary to carry a die in a capstan, turret, feed-spindle, or other medium has ample clearing holes for swarf escape, and may or may not include the means of adjusting. Combination holders are

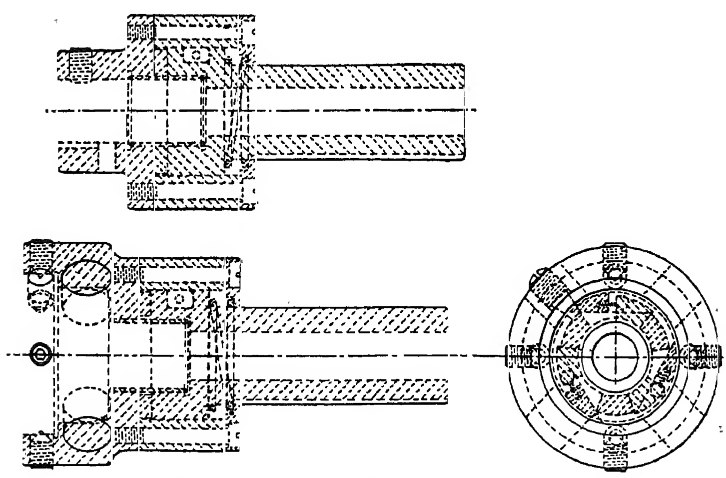


Fig. 28.—H. W. Ward self-releasing tap and die-holders.

sometimes required, having a telescopic construction, enabling one die to be mounted at the front and another in the body behind it, or a tap can be installed instead of a die. Dies of different pitches are allowed for by the telescopic arrangement, with springs added, permitting each die to follow its pitch.

Self-releasing Tap and Die-holders.—To enable cutting to an end and backing away to be done as a spindle is reversed, a double clutch mechanism is built into the holder, the same being used for taps if an adapter is fitted, or the design may suit for taps specially. The principle is similar in various makes, but the form of clutch chosen differs. Examples from three firms' practice are given in the illustrations. Fig. 27 is by Charles Taylor (Birm.) Ltd., Birmingham, and as threading commences the pairs of pegs A, B hold the die stationary until the capstan stops feeding, whereupon the pegs draw apart, leaving the die free to

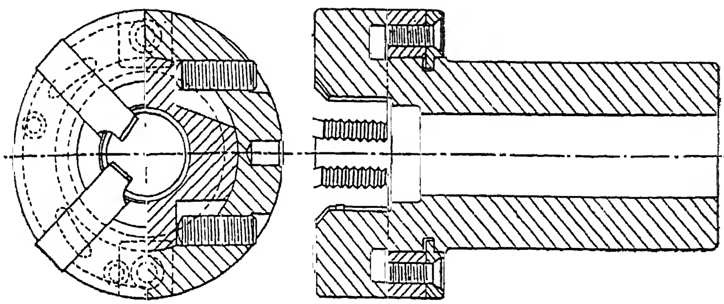


Fig. 29.—Adjustable die with size control by regulating the two screws.

revolve with the work. When the spindle reverses, hardened rollers C catch in curved slots in the body, making a gentle, shockless engagement, and the die-holder is again prevented from rotating. The object of dowel D is to go in a hole in the capstan face and take the driving stress, thus avoiding need to grip the shank very hard.

In the H. W. Ward & Co., Ltd., types (Fig. 28) a dog clutch takes the forward drive, a spiral spring maintaining the engagement. As the portions draw apart and the spindle reverses, the roller clutch comes into action. An adapter can be

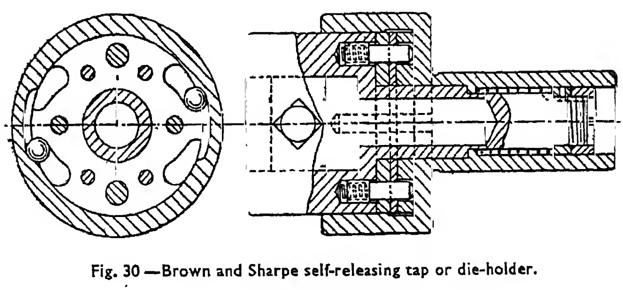


Fig. 30.—Brown and Sharpe self-releasing tap or die-holder.

inserted in the die socket to hold larger or smaller dies, or a tap adapter bush may be substituted to carry taps, while the proper releasing tap-holder can be suited for smaller taps by insertion of an adapter bush, which has a clearing hole for the binding screw to reach through to the tap shank.

Comparison of the Brown & Sharpe non-releasing and releasing holders may be observed from Figs. 31 and 30. The first named (Fig. 31) has keys which allow of sliding (but not rotation), and at withdrawal the coiled spring pulls the body

right back into the shank. The tap goes in the adapter bushing, or if a die is used this is fixed in a hood secured by a set-screw on the body. When two taps or dies are employed, for roughening and finishing, the latter kind of holder is constructed as at A, a pair of spring plungers being added to cushion the tool when brought into contact with the work until it catches in the roughened-out thread. In Fig. 30 two spring plungers keep the holder still until turret feed stops and the plungers pull out of mesh. As the body starts revolving in the opposite direction, two steel balls fly outwards and become wedged in the cam

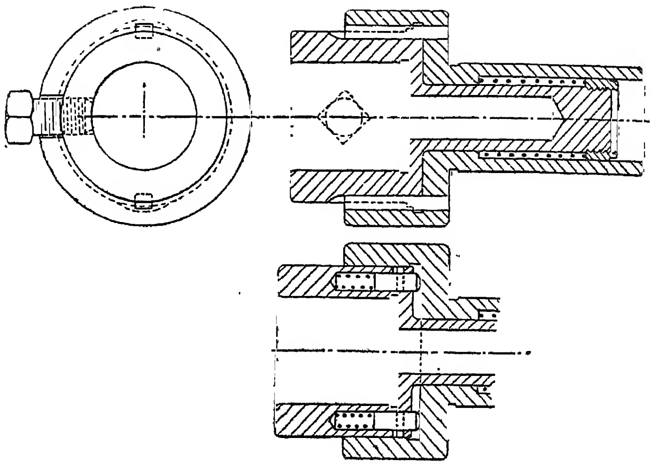


Fig. 31.—Brown and Sharpe non-releasing tap or die-holder.

pockets. For threading the reverse hand the balls must be changed into the other pair of pockets.

The correct use of machine taps and dies, particularly as to speeds and coolants, and the direction of the jet of coolant, has an important bearing on their life and the accuracy of the work they produce. For this reason manufacturers have their advisory staffs on threading problems, and issue instruction books which deal very fully with the normal run of threading problems. Great attention must be paid to the correct grinding of taps and dies to suit the work and the material.

Calculating Helix Angle of Screw Threads.—The calculation for helix angle of screw threads is usually made on the effective diameter of the thread in question.

The calculation is as follows:

Let D = Effective diameter of thread.

p = Pitch in inches.

θ = Helix angle.

Then:

$$\operatorname{Tan} \theta = \frac{p}{\pi D}$$

In the case of a square thread the effective diameter in the above calculation would be replaced by the mean diameter, i.e. outside diameter, less depth of thread.

The diameter of cutters does not enter into the calculation, but better results are obtained with smaller cutters than with larger ones.

With multi-start threads the pitch is taken as the advance in one revolution of any particular thread, or, in other words, the "lead."

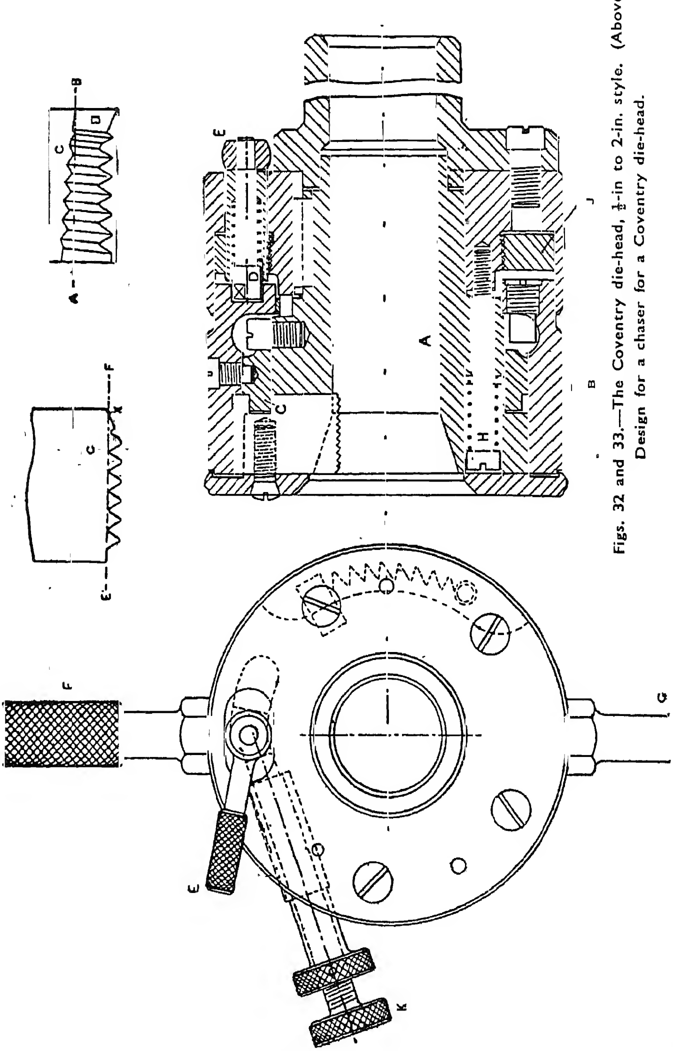
Opening die-heads for machine use are utilised to a far greater degree than the dies hitherto illustrated, because the chasers can be made and reground accurately, they release off the thread at the termination ready for quick withdraw, exact sizes can be set, or roughening and finishing passes provided for if required. Rotating and non-rotating types are supplied, and some have floating action to follow the work freely. Diameters as small as $\frac{1}{8}$ in. can be cut, also tapers either by taper chasers, or an attachment which causes the chasers to open gradually, the latter for long screws. Two diameters may be screwed by one set of chasers. The opening motion of a die-head is variously effected according to the kind of machine it is mounted on, the devices comprising an internal stop struck by the end of the work, a projection striking a trip mechanism which produces a sliding action to free the chasers, and arrest of the travel of the slide carrying the die-head, whereupon the front of the head draws out and releases the chasers.

The Coventry Die-head.—Messrs. Alfred Herbert, Ltd., make two main types, one with flat chasers, the other with tangential, designated as Coventry and Tangic respectively. In the former the four chasers go in slots in the body (A, Fig. 32), and are retained by the front plate, which releases by slackening the screws and giving a slight twist. The radial position of the chasers is controlled by external and internal scrolls (B, C), which are held together by screws. The opening action occurs at arrest of the forward motion of die-head (or work); the dies continue to screw themselves forward until the scroll B is pulled off the detent-pin D, whereupon opening springs disposed in the annular recess of B make the dies open instantly. Hand-opening can be done by pulling out the detent-pin handle E after relieving the pressure of the opening springs by pushing the closing handle F. For automatic closing, the handle G is provided. Return of the scroll B occurs by the pressure of the springs under the heads of two screws H. Member J is the adjusting ring, to which the shank is attached by screws, and the body A slides in it by two keys. Roughing and finishing cuts are taken by throwing over the handle E, so affecting the setting of the detent-pin; this pin has two flats at different distances from its axis, and engages in a hard-steel tooth let into the back of the scroll, holding it in the one or other setting according to the location of the handle.

A somewhat different mode of regulation is fitted to the larger die-heads. Diameter adjustment is controlled by the tangential adjusting screw K, which should nominally make the dies cut correct size when an indicator line is at zero in relation to a scale, and the handle E is at the finishing position. For some kinds of auto-screw machine work, a spring holder is employed which allows of slight yielding to give a good start.

Taper Threading.—For short tapers, of not more than 4 degrees including angle, use is made of taper dies, which cut along their whole length, and when quick cutting four slight ridges are left along the thread, but these do not matter for ordinary purposes. Steeper and longer tapers are done by means of an attachment which carries a former-bar and former. As the die-head travels forward and the former remains stationary, an inclined slot in the latter engages with a projection on a plate clamped to a vertical rack, which thus slides and rotates the die-head scroll through a gear segment fastened to it. The outward movement of the dies is thus positively controlled. The threads are finished quite round and smooth without the ridges left by taper dies, and there is no danger of causing strains by running the work too far into the dies.

Die-head Mountings.—Various methods have to be followed for mounting the heads on capstan and turret lathes, and different classes of screw machines and drilling machines, etc., in non-rotating or rotating manner, and the trip and closing devices vary. When the swing over a capstan slide prevents the use of a die-head of the required size, an elevating holder is applied. The front portion of this has a sliding motion, performed by a handle, so that the die may be raised during the indexing, and dropped again to a dead stop. If the production time is low, automatic elevation by means of a cam on top of the capstan is preferred, and a spring effects return.



Figs. 32 and 33.—The Coventry die-head, ½-in to 2-in. style. (Above) Design for a chaser for a Coventry die-head.

Types of Chaser.—For all ordinary demands straight-cut dies are used, while for precision cutting to close tolerances Zonic lapped dies are chosen, these being lapped for a considerable distance behind the cutting edge. For the best results threads should be roughed out by a head with straight-cut dies, and finished by one with Zonic dies. Fig. 33 explains the action of the chasers, line A–B representing the work axis. The cutting face C is at an angle thereto, thus part of the cutting face is above the centre. The taper face D is ground on the front, and cutting occurs only on the top edge of this face, and a little to the right and left of point X where a line E–F tangential to the bottom of the threads intersects

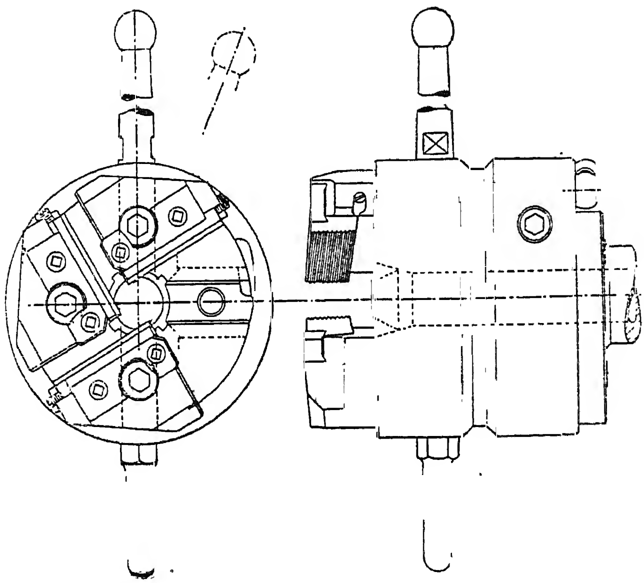


Fig. 34.—The Tangic die-head.

the cutting edge of face D. The rest of the threads above the line A–B act as a nut and furnish a self-guiding motion which ensures accurate pitch. When sharpening, only face D is ground. After several grindings the width of the taper face will increase, bringing the point X farther from the front of the die and above line A–B. The edge will then not cut properly because it is too high. Correction is made by grinding face C to bring X back to its proper position. Fixtures are utilised to set the chasers for sharpening and get proper angles for dealing with different materials.

Throat Angle.—The life of the dies will be increased and cutting rendered easier if a suitable clearance undercut is given, either a radiused neck or a square cut, or one bevelled on the outer side. For ordinary purposes a throat angle of 20 degrees is standard, but on very tough materials or coarse threads a long throat angle of 15 degrees is better, distributing the cutting over more threads, and prolonging the life. If cutting close up to a shoulder happens to be unavoidable,

a 33-degree throat angle is necessary, but the edges wear more rapidly on hard materials. A good plan is to take a second cut with another head should close accuracy be required. Occasionally, projecting chasers must be used, if anything on the work or chuck jaws interferes with the front plate.

Threading Speeds and Coolant.—Conditions, threads, and materials vary widely, but an approximate statement as to speeds is:

Tough steel, 5 to 8 ft. per minute; general mild-steel work, 10 to 20 ft.; free-cutting bolt steel, 25 to 50 ft.; cast iron, 10 to 15 ft.; brass and copper, speeds as for turning.

A soluble oil or other compound should be applied in order to ease the action, prolong die life, and impart good finish.. The best scheme when practicable is to run a flow through the shank, washing the swarf out and keeping the working parts free from sediment.

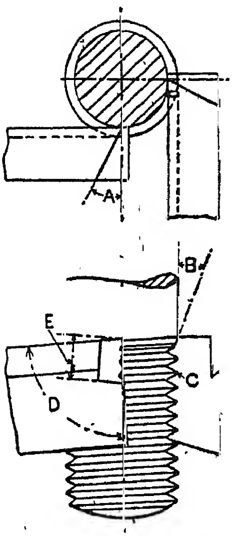


Fig. 35.—The Tangic die-head.

Tangic Die-heads.—For long runs and on difficult materials a head having tangential dies is manufactured, these being ground on the end only, on a fixture which enables any top rake or throat angle to be obtained. Inner and outer scrolls affect the radial positions of the die-holders, and on the draw-off action a detent-pin operates as before described. Roughening and finishing cuts are also arranged by moving the detent-pin handle to right or left, and fine regulation for diameter is further provided through adjusting screws. The dies are held at the correct helix angle by the holders (Fig. 34), which have end adjustment screws and clamping plates. A setting gauge enables the dies to be located.

The chasers have to be ground differently according to whether the threads are cut without using a lead screw, in which event the pitch has to be contrôlled by the guidance of the non-cutting portion, or whether they are cut with the control of a lead screw, when the pitch-controlling feature is eliminated. A difference also appears in taper dies for short tapers, and those for longer, which act under the coercion of a taper attachment.

The grinding and attitude of the chasers are depicted in Fig. 35, where A is the cutting angle, B the throat angle, C the first full thread, and D the lead angle. The length E of cutting angle must include the first full thread of the die. The angle which the cutting angle must make with the side of die to bring the thread portion of cutting angle parallel with centre line as shown depends on the angle of throat chosen. Two classes of chaser are supplied, lapped for ordinary commercial limits, and super-lapped for working to fine limits.

Collapsible Taps.—Two types of collapsible taps are available, one with receding motion for taper threads, the other more familiar style collapsing for quick withdrawal. The Coventry collapsing taps are of the latter type, and have close size regulation, roughing and finishing device by lever movement, and pull-off trip. The cutting and self-guiding features of the chasers are much like those of the chasers of the Coventry die-heads.

Fig. 36 illustrates the Murchey collapsible tap, which can be arranged for either non-rotating or rotating service. The chasers hook into seatings in the centre-pin, thus when the latter recedes the chasers collapse. The tripping occurs as ring A touches the work face, and the arrested motion causes depression of trips B B by their tapered ends, releasing their bearing on trip-collar C. Member D is then free to jump back under the pressure of springs E, and the central adjusting

screw pulls the centre-pin. Adjustment for diameter is obtained by passing a wrench through the locking-screw F after loosening it and turning as required, afterwards tightening F.

It will be seen that collapsible taps and dies are somewhat similar in principle, the main difference being that the actions are reversed. Collapsible taps considerably reduce tapping times, and do not spoil the thread, as non-collapsing taps sometimes do on the withdrawal.

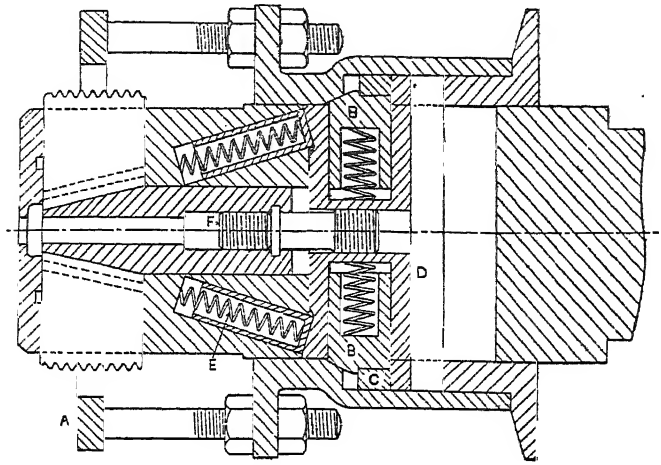


Fig. 36.—Details of the Murchey collapsible tap.

Combination taps and dies are sometimes used. These cut internal and external threads at the same time, even when the pitches are different. This is compensated for by means of a floating action of the die or the tap.

Adjustable taps are now used for accurate work. Thus tap wear may be taken up, and accurate threads produced through the life of the tap.

Tap and die manufacturers have adopted standards for the overall length, length of thread, diameter of shank, and size of square of taps; the British Standards Institution do not issue a standard for tap dimensions, although B.S. 45 is issued for sparking-plug holes for automobile engines.

The reader is directed to two handbooks published by the publishers of the present volume, entitled *Screw Thread Manual* and *Screw Thread Tables*. Manufacturers of die-heads and tappers issue special instructions for the use of their equipment in connection with special threading problems which may be encountered on some of the special alloys, such as Electron, magnesium, duralumin, and some of the specially alloyed non-ferrous metals.

Tap and die proportions have been standardised by the British Tap and Die Manufacturers' Association.

For all forms of tap and die threading lard oil is the best lubricant. The soluble oil mixture, although possessing the advantage of a greater specific heat than lard oil and thus being more efficient as a coolant, is not sufficiently good as a lubricant to deal with the long chips that accumulate when threading. On brass rod, however, and similar materials where the work is done at a comparatively high speed, the cooling properties of the soluble oil possibly outweigh its other disadvantages, and its use is permissible on these materials.

For screw-cutting with a single-point tool or chase, lard oil should always be used on steel, and a lard oil and paraffin mixture on aluminium and its alloys. Other materials can be cut dry or with the soluble oil mixture.

Solid or adjustable dies are employed in small screwing machines, which have plain jaws for rod or false ones for shaped articles. Objects which are not finished on capstan lathes can thus be dealt with, and the operation is conducted more quickly and accurately than by hand-controlled dies. In other cases opening die-heads are used and a wide range of machine designs is available for various sizes and classes of work-rods, bars, bolts, stays, castings, pipes, and forgings. The ordinary flat radial chasers are set in a head which has cam surfaces to control the positions; sizing and quick opening, by hand or automatically, are thus provided for. Single and duplex-type machines are constructed, and some have lead screws and change gears to ensure accurate pitch, such as for boiler stays and other important subjects. Cut-off attachment is fitted on pipe machines. The number of dies in a set for ordinary circumstances is four, but six or eight occur in the larger sizes of pipe machines.

Tangential Die-heads.—The advantages of tangential dies in long life, avoidance of need for re-cutting or hobbing, simplicity of grinding, and the rigid mode of holding make them highly favoured for screwing machines of all types

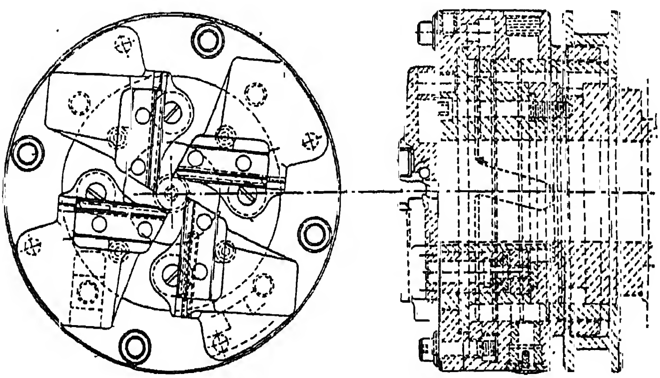


Fig. 37.—Tangential die-head of Kendall and Gent screwing machine.

which were formerly only built to use flat chasers. Some firms supply both kinds, others only make the tangential style. The series by Kendall and Gent (1920) Ltd., Manchester, have only tangential heads and cover a range from ¼-in. bolts to 18-in. tubes. The chase holders (Fig. 37) have shanks which are firmly centred in the body of the head, but can swivel, so as to come under the action of the grooved sliding collar, moving on keys and through the connections to come to the desired diameter. Adjustment for sizing may be done whilst the machine is running, and roughing and finishing settings are provided for through the medium of an eccentric handle. For automatic opening a stop-rod struck by the carriage moves the die-head control lever. A tapering mechanism is also arranged for. A lead screw of modified Acme form, with rounded corners to facilitate engagement, is employed for coarse-pitch threads, some of special form or those demanding accurate lead. The carriage slides on round chromium-steel bars, ensuring maintenance of alignment and clean surfaces. Fixtures are mounted on the carriage for repetition objects not suitable to hold in the regular vice. Sometimes a two-position fixture has to be used to bring a pair of screwed units into alignment successively.

The chasers are of super high-speed steel, the rake (Fig. 38) being varied to suit different materials. An approximate guide is given in the table below.

A fixture with universal swivel movement is used to hold the chaser at the specified angle for sharpening, and a gauge serves to set each chaser at the correct cutting position in its holder. If the chasers are set too far forward they will form the thread by pushing instead of cutting, with resultant heating and wear, and the threads may also be tapered. Should the chasers be set behind centre they tend to dig in, produce out-of-round threads, and the cutting edges will probably chip. The same chasers will cut left-hand threads, being ground at the opposite end, and placed in left-hand holders.

Material	*Rake Angle*
Cast brass	5 deg. negative.
Drawn brass	10 ,, to 22 deg. positive.
Cast iron	15 ,, positive.
Wrought iron	18 ,, ,,
Malleable iron	18 ,, ,,
Cast aluminium	10 ,, ,,
Drawn aluminium	28 ,, to 33 deg. positive.
Bronze	10 ,, positive.
Seamless steel tubing	25 ,, ,,
Steel	25 ,, ,,
Nickel steel, annealed	25 ,, ,,
Nickel steel, heat-treated	18 ,, to 22 deg. positive.
Monel metal	28 ,, positive.
Copper	28 ,, ,,
Manganese bronze	0 ,, to 10 deg. positive.
Bakelite	Zero.

Machine Tapping.—In addition to tapping in the capstan and turret lathes, and automatics, the operation is effected in screwing machines, nut tappers, tapping machines of various standard or special kinds, drilling and boring machines, and portable outfits. In many machines lead-screw control is incorporated, and multi-spindle designs are commonly used. Studding is added to many sorts of machines, while some automatically insert screws from a feeding device. The nut tappers use long shank taps, or those with bent shanks, from which the string of nuts is removed as filled. An auto-trip mechanism comes into action in some cases to throw in mechanical reverse, or perhaps electrical, but numbers of tappers embody instantaneous friction reverse through clutches. On mass-production, multi-spindle machines have work-carriers which only have to be kept loaded, the sequence going on automatically. The carriers are either dial, drum, conveyer, or push type, according to the class of pieces dealt with.

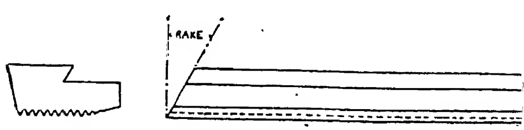


Fig. 38.—Chaser for the die-head.

Tapping Attachments.—These are of two main types, those with friction drive adjusted to slip before the danger point, and others with reverse added. The friction is usually by fibre or other clutch faces, but the long-established Pearn tapper (Fig. 39) (Herbert Hunt & Sons, Manchester) has shallow claw clutches with sloped faces to disengage when the spring above is unable to keep them together. The tension is set by turning the nut at the top, the spindle being indexed for each size of tap. The taps are driven by a groove in the shank and held in by the spring bolt.

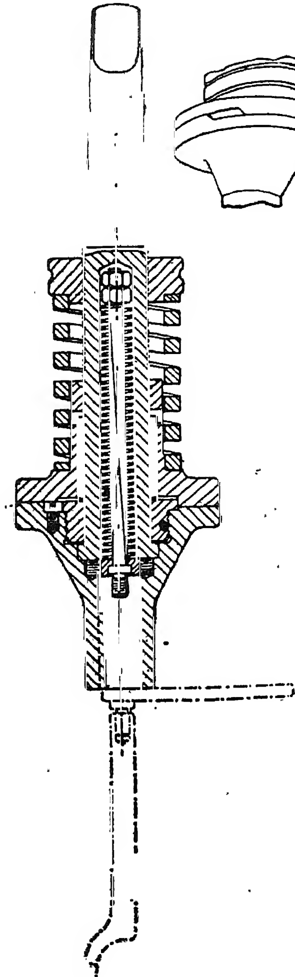


Fig. 39.—Pearn tapper (H. Hunt & Sons).

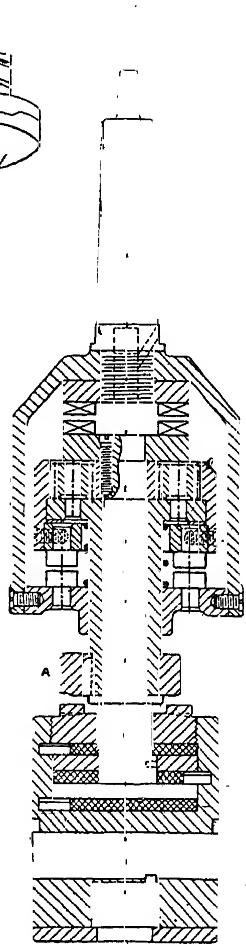


Fig. 40.—Wharton tapping attachment (Wearden and Guylee Ltd.).

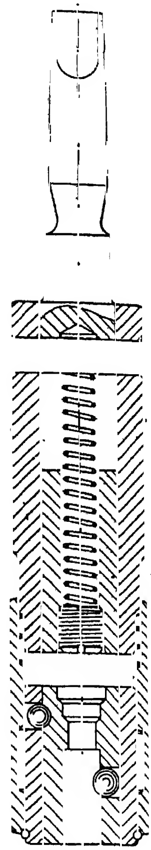


Fig. 41.—Tap holder with forward float to ensure correct lead.

Reversing Tapper.—If the machine has no reverse motion, a reversing attachment must be used. The Hunt style (Fig. 42), by the firm just mentioned, has the aluminium-alloy body fitted with a bar to touch the slide or column of the machine and prevent rotation. The tap spindle has a chuck with a pair of floating jaws which grip the square end, and there are three cone jaws which may be adjusted to hold the shank and centre it, but the floating jaws do the driving. A cone (A) at the top of the spindle is lined with leather inside and out, and when pressure is brought on to this spindle it causes the outer surface of the cone to come into contact with the revolving cone B. When the spindle is pulled downwards the inner face of the cone contacts with C. Cone B is driven direct from

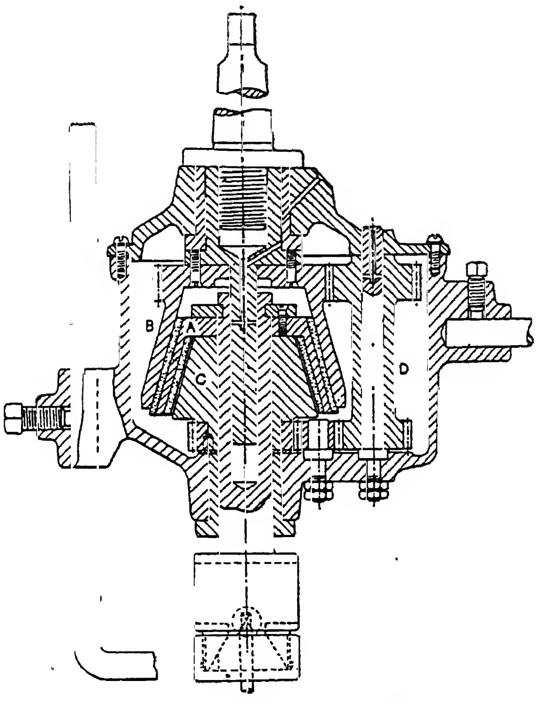


Fig. 42.—Hunt reversing tapper.

the shank of the tapper, and has a gear ring on it driving countershaft D, which, through an intermediary gear, imparts the reverse motion to C. Therefore, as the tap engages with the work the frictional drive gradually starts the tap, and at the required depth the operator raises the spindle and the other clutch gives high-speed reverse. The bar at the side is set to act as a gauge for determining the depth.

The Wharton Tapping Attachment.—Fig. 40 has a friction drive just above the tap-holding chuck, and below the gears, ensuring protection against damage to these should any overstrain be applied to the tap in either direction. Adjustment is made to suit the size of tap, by easing or tightening the tension ring above the washers. The tension is first set until the tap slips under the cut, then the

ring is screwed down sufficiently to drive under normal cut. An arm (A) is keyed to project out and carry an arrester rod as usual, touching some part of the machine to prevent rotation of the casing. A spring-fitted depth-gauge rod also goes in the arm (though not shown in the drawing), and as it reaches the required depth the result is to stop the feed of the machine spindle and the upper clutches unmesh. On lifting the machine spindle the other clutch is engaged and the gears cause backing out in the ratio of 2 to 1. If required, the tap may be repeatedly reversed, lubricated, and fed in again to the desired depth. The chuck has duplex floating jaws, the top ones gripping and turning on all four corners of the tap square and centralising one way. The bottom jaws grip the round shank and centralise at right angles to the top jaws. This attachment is manufactured by Wearden & Guylee Ltd., Sheffield.

Tapper with Oscillating Action.—The Wahlstrom attachment embodies mechanism by which a change can be given from the continuous rotation suitable for soft metals and easy cutting to an oscillating motion for difficult cases. By turning a knob the tap is given a to-and-fro movement in imitation of hand-working.

Tap-holder with Forward Float.—In Fig. 41 the principle of forward float is incorporated, this being a holder for single- or multi-spindle tappers. The tap has a groove ground across it to fit the ball in the collet, and the squared end goes in the square hole. The collet is retained by the other ball catch, secured by pulling down the outer sleeve, and a cross-pin revolves the collet by a slot across its end. The cross-pin at the top transmits the motion from the shank to the holder, but there is longitudinal float to allow for tapping holes of unequal lead. The necking-in of the shank is for the purpose of taking the set-screw that retains it in the drill spindle.

Useful Screw-thread Data.—A full depth of thread requires three times the power to produce 75 per cent. of the full thread depth, yet the full thread depth is only 5 per cent. stronger.

To ensure economical production, provide a minimum of 50 per cent. and a maximum of 75 per cent. of the full thread depth according to the material being worked and length of tapped hole. The harder and tougher the material and the deeper the tapping, the larger the tapping drill that may be safely used. Soft, tough materials, such as copper, aluminium, etc., require a larger tapping drill than cast metals, as when tapping tenacious material the metal is drawn to the top of the thread, thus increasing the thread depth produced. This is particularly evident when the tap has slightly dulled.

Recommended Percentage of Full Thread Depth (Theoretical): Copper and aluminium 60 to 65 per cent., steel 65 to 70 per cent., hard brass 70 to 75 per cent. When depth of tapped hole is more than one and a half times screw diameter, divide the mean of above percentages by 1·25 to obtain reduced figure, i.e. mean of 70 and 75 = 72·5, therefore $\frac{72\cdot5}{1\cdot25} = 58$ per cent.

Formulæ: The percentage of the full thread depth $= 100 - \left\{\frac{D - C}{M - C} \times 100\right\}$, when D = tapping drill used (in decimals), C = minor diameter of thread, M = major diameter of thread.

To find the tapping drill for a specified percentage of the full thread depth, use the following:

$$\text{Tapping drill} = C + \left(\frac{T}{100}\right)(100 - P),$$

when C = minor diameter, T = double depth of thread, P = percentage required.

WHITWORTH STANDARD HEXAGON NUTS AND BOLTS

Diam.	*Hexagonal Nuts*		*Thickness of Bolt Heads*	*Diam.*	*Hexagonal Nuts*		*Thickness of Bolt Heads*
	Across Flats	*Across Corners*			*Across Flats*	*Across Corners*	
	In.				*In.*		
1/8	0·338	0·390	0·1093	2 3/4	4·18	4·82	2·4062
3/16	0·448	0·517	0·164	2 7/8	4·34	5·02	2·5156
1/4	0·525	0·606	0·2187	3	4·53	5·23	2·625
5/16	0·601	0·694	0·2734	3 1/8	4·69	5·41	2·7343
3/8	0·709	0·819	0·3281	3 1/4	4·85	5·6	2·8256
7/16	0·820	0·947	0·3828	3 3/8	5·01	5·78	2·9531
1/2	0·920	1·06	0·4375	3 1/2	5·17	5·98	3·0624
9/16	1·01	1·16	0·4921	3 5/8	5·36	6·19	3·1718
5/8	1·1	1·27	0·5468	3 3/4	5·55	6·41	3·2812
11/16	1·2	1·38	0·6016	3 7/8	5·75	6·64	3·3906
3/4	1·3	1·5	0·6562	4	5·95	6·87	3·5
13/16	1·39	1·6	0·7064	4 1/8	6·16	7·11	3·6094
7/8	1·48	1·7	0·7656	4 1/4	6·37	7·36	3·7046
15/16	1·57	1·82	0·8203	4 3/8	6·60	7·62	3·8271
1	1·67	1·93	0·875	4 1/2	6·82	7·88	3·9374
1 1/8	1·86	2·15	0·9843	4 5/8	7·06	8·15	4·0469
1 1/4	2·05	2·36	1·0937	4 3/4	7·30	8·43	4·1562
1 3/8	2·21	2·55	1·2031	4 7/8	7·55	8·72	4·2656
1 1/2	2·41	2·78	1·3125	5	7·80	9·01	4·375
1 5/8	2·57	2·97	1·4128	5 1/8	8·06	9·31	4·4844
1 3/4	2·75	3·18	1·5312	5 1/4	8·35	9·64	4·5926
1 7/8	3·02	3·48	1·6406	5 3/8	8·60	9·93	4·7031
2	3·15	3·63	1·75	5 1/2	8·85	10·22	4·8124
2 1/8	3·34	3·85	1·8523	5 5/8	9·15	10·57	4·9218
2 1/4	3·54	4·09	1·9687	5 3/4	9·45	10·91	5·0312
2 3/8	3·75	4·33	2·0781	5 7/8	9·75	11·26	5·1406
2 1/2	3·89	4·49	2·1875	6	10·00	11·55	5·25
2 5/8	4·05	4·67	2·2968				

Admiralty Fine Thread (Whitworth Form). (Obsolete)

Diam., in.	*Threads per in.*	*Diam., in.*	*Threads per in.*	*Diam., in.*	*Threads per in.*	*Diam., in.*	*Threads per in.*
3/8	24	11/16	20	1	12	1 5/16	12
7/16	24	3/4	14	1 1/16	12	1 3/8	12
1/2	20	13/16	14	1 1/8	12	1 7/16	12
9/16	20	7/8	14	1 3/16	12	1 1/2	12
5/8	20	15/16	14	1 1/4	12		

Above 1 1/2 in.: as may be approved.

BRITISH STANDARD FINE 55° ANGLE

Class "A" (Close Fit)

Screw Dia.	*Tapping Drill*	*Decimal*	*Tolerance*	*Minor Dia.*	*T.P.I.*	*Double Depth of Thread*	*Pitch*	*B.S.I. Minor Dia Tolerance*	*Effective Dia.*	*Major Dia.*	*Clearing Drill*	*Decimal*	*Tolerance*
7/32	No. 16	0·1770	0·0039	0·1731	28	0·0457	0·03571	0·0111	0·1959	0·2188	No. 2	0·2210	0·0022
1/4	13/64	0·2031	0·0024	0·2007	26	0·0492	0·03846	0·0117	0·2254	0·2500	6·40 mm.	0·2520	0·0020
9/32	Letter A	0·2340	0·0020	0·2320	26	0·0492	0·03846	0·0117	0·2566	0·2813	7·20 mm.	0·2835	0·0022
5/16	Letter F	0·2570	0·0027	0·2543	22	0·0582	0·04545	0·0141	0·2834	0·3125	Letter O	0·3160	0·0035
3/8	8·0 mm.	0·3150	0·0040	0·3110	20	0·0640	0·05000	0·0170	0·3430	0·3750	9·60 mm.	0·3780	0·0030
7/16	9·40 mm	0·3701	0·0037	0·3664	18	0·0712	0·05556	0·0181	0·4019	0·4375	11·20 mm.	0·4409	0·0034
1/2	10·80 mm.	0·4252	0·0052	0·4200	16	0·0800	0·06250	0·0195	0·4600	0·5000	12·80 mm.	0·5039	0·0039
9/16	12·40 mm.	0·4882	0·0057	0·4825	16	0·0800	0·06250	0·0195	0·5225	0·5625	14·50 mm.	0·5709	0·0084
5/8	N.S.	0·5380	0·0045	0·5335	14	0·0914	0·07143	0·0213	0·5793	0·6250	16·0 mm.	0·6299	0·0049
11/16	N.S.	0·6005	0·0045	0·5960	14	0·0914	0·07143	0·0213	0·6418	0·6875	N.S.	0·6935	0·0060
3/4	16·50 mm	0·6496	0·0063	0·6433	12	0·1068	0·08330	0·0237	0·6966	0·750	N.S.	0·7575	0·0075
7/8	49/64	0·7656	0·0070	0·7586	11	0·1164	0·09091	0·0252	0·8168	0·8750	22·50 mm.	0·8858	0·0108
1	7/8	0·8750	0·0031	0·8719	10	0·1281	0·100	0·0270	0·9360	1·0000	N.S.	1·0100	0·0100
1 1/8	N.S.	0·9897	0·0070	0·9827	9	0·1422	0·11111	0·0292	1·0539	1·1250	N.S.	1·1360	0·0110
1 1/4	N.S.	1·1147	0·0070	1·1077	9	0·1422	0·11111	0·0292	1·1789	1·2500	1 17/64	1·2656	0·0156
1 3/8	31·0 mm.	1·2205	0·0056	1·2149	8	0·1600	0·1250	0·0320	1·2950	1·3750	1 25/64	1·3906	0·0156
1 1/2	N.S.	1·3480	0·0081	1·3399	8	0·1600	0·1250	0·0320	1·4200	1·5000	1 33/64	1·5156	0·0156
1 3/4	40·0 mm	1·5748	0·0078	1·5670	7	0·1630	0·1429	0·0356	1·6585	1·7500	1 49/64	1·7656	0·0156
2	1 53/64	1·8281	0·0111	1·8170	7	0·1830	0·1429	0·0356	1·9085	2·0000	2 1/64	2·0156	0·0156

Polishing-spindle Speeds

The speed at which brushing wheels are revolved is an important matter. It should be remembered that wire wheels must always run more slowly than bristle or fibre wheels; also that the larger the wheel and the coarser the wire, the more slowly must it revolve. The following speeds are recommended for average working conditions:

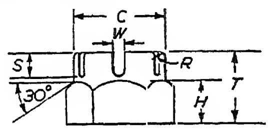
Small bristle and fibre wheels	2500 r.p.m.
Large bristle and fibre wheels	2000 r.p.m.
Fine-wire scratch wheels	1600–1700 r.p.m.
Medium-wire scratch wheels	1200–1500 r.p.m.
Coarse-wire scratch wheels	700–1000 r.p.m.
Extra heavy-wire scratch wheels	500–600 r.p.m.

BRITISH ASSOCIATION (B.A.) 47° 30′ ANGLE
Class "C" (Free Fit)

B.A. No.	Tapping Drill	Decimal	Tolerance	Clearing Drill	Decimal	Tolerance
12	No. 59	0·0410	0·0031	No. 54	0·0550	0·0039
11	1·20 mm.	0·0472	0·0027	$\frac{1}{16}$	0·0625	0·0034
10	No. 54	0·0550	0·0047	1·80 mm.	0·0709	0·0040
9	1·55 mm.	0·0610	0·0046	No. 47	0·0785	0·0037
8	1·85 mm.	0·0728	0·0064	2·30 mm.	0·0906	0·0040
7	No. 45	0·0820	0·0062	No. 37	0·1040	0·0056
6	2·35 mm.	0·0925	0·0073	No. 32	0·1160	0·0058
5	No. 36	0·1065	0·0083	3·40 mm.	0·1339	0·0079
4	No. 31	0·1200	0·0095	No. 25	0·1495	0·0078
3	No. 29	0·1360	0·0090	No. 18	0·1695	0·0081
2	4·0 mm.	0·1575	0·0107	No. 10	0·1935	0·0085
1	No. 15	0 1800	0·0137	$\frac{7}{32}$	0·2186	0·0099
0	No. 7	0·2010	0·0120	Letter D	0·2460	0·0098

BRITISH STANDARD CASTLE NUTS

T = 1·25 D.
H = 0·75 D.
S = 0·4375 D.
W = 0·25 D, where D = full diameter of thread on bolt.
C = (width across flats) − $\frac{1}{16}$ in.



Diameter of Bolt	Overall Dimensions of Nut (in.)								Dimensions of Slot	
	Width Across Flats		Approx. Width Across Corners	Total Thickness	Thickness of Hexagon	Thickness of Cylinder	Diameter of Cylinder	Rounding Edge of Cylinder	Width	Depth
	Max.	Min.	(Max.)	T	H	T-H	C	R	W	S
$\frac{1}{4}$ in.	0·525	0·520	0·61	0·31	0·19	0·12	0·45	0·03	0·063	0·11
$\frac{3}{8}$ in.	0·710	0·705	0·82	0·47	0·28	0·19	0·64	0·05	0·094	0·16
$\frac{1}{2}$ in.	0·920	0·915	1·06	0·63	0·38	0·25	0·85	0·06	0·125	0·22
$\frac{5}{8}$ in.	1·100	1·092	1·27	0·78	0·47	0·31	1·02	0·08	0·156	0·27
$\frac{3}{4}$ in.	1·300	1·292	1·50	0·94	0·56	0·43	1·40	0·11	0·219	0·38
1 in.	1·670	1·662	1·93	1·25	0·75	0·50	1·590	0·13	0·250	0·44
$1\frac{1}{8}$ in.	1·860	1·850	2·15	1·41	0·84	0·57	1·780	0·14	0·281	0·49
$1\frac{1}{4}$ in.	2·050	2·040	2·37	1·56	0·94	0·62	1·97	0·16	0·313	0·55
$1\frac{1}{2}$ in.	2·410	2·400	2·78	1·88	1·13	0·75	2·33	0·19	0·375	0·66
$1\frac{3}{4}$ in.	2·760	2·750	3·19	2·19	1·31	0·88	2·68	0·22	0·438	0·77

STANDARD BRASS THREAD 55° ANGLE

Class "A" (Close Fit)

Screw Dia.	*Tapping Drill*	*Decimal*	*Tolerance*	*Minor Dia.*	*T.P.I.*	*Double Depth of Thread*	*Pitch*	*B.S.I. Minor Dia. Tolerance*	*Major Dia.*	*Clearing Drill*	*Decimal*	*Tolerance*
$\frac{1}{8}$	$\frac{5}{64}$	0·0781	0·0023	0·0758	26	0·0492	0·03846	0·0117	0·1250	3·20 mm.	0·1260	0·0010
$\frac{3}{16}$	$\frac{9}{64}$	0·1406	0·0023	0·1383	26	0·0492	0·03846	0·0117	0·1875	4·80 mm.	0·1890	0·0015
$\frac{1}{4}$	$\frac{13}{64}$	0·2031	0·0023	0·2008	26	0·0492	0·03846	0·0117	0·2500	6·40 mm.	0·2520	0·0020
$\frac{5}{16}$	$\frac{17}{64}$	0·2656	0·0023	0·2633	26	0·0492	0·03846	0·0117	0·3125	Letter O	0·3160	0·0035
$\frac{3}{8}$	$\frac{21}{64}$	0·3281	0·0023	0·3258	26	0·0492	0·03846	0·0117	0·3750	9·60 mm.	0·3780	0·0030
$\frac{7}{16}$	$\frac{25}{64}$	0·3906	0·0023	0·3883	26	0·0492	0·03846	0·0117	0·4375	11·20 mm.	0·4409	0·0034
$\frac{1}{2}$	$\frac{29}{64}$	0·4531	0·0023	0·4508	26	0·0492	0·03846	0·0117	0·5000	12·80 mm.	0·5089	0·0039
$\frac{5}{8}$	$\frac{37}{64}$	0·5781	0·0023	0·5758	26	0·0492	0·03846	0·0117	0·6250	16·0 mm.	0·6299	0·0049
$\frac{3}{4}$	$\frac{45}{64}$	0·7031	0·0023	0·7008	26	0·0492	0·03846	0·0117	0·7500	N.S.	0·7575	0·0075
$\frac{7}{8}$	$\frac{53}{64}$	0·8281	0·0023	0·8258	26	0·0492	0·03846	0·0117	0·8750	22·50 mm.	0·8858	0·0108
1	$\frac{61}{64}$	0·9531	0·0023	0·9508	26	0·0492	0·03846	0·0117	1·0000	N.S.	1·0100	0·0100
$1\frac{1}{8}$	$1\frac{5}{64}$	1·0781	0·0023	1·0758	26	0·0492	0·03846	0·0117	1·1250	N.S.	1·1360	0·0110
$1\frac{1}{4}$	$1\frac{13}{64}$	1·2031	0·0023	1·2008	26	0·0492	0·03846	0·0117	1·2500	$1\frac{17}{64}$	1·2656	0·0156
$1\frac{1}{2}$	$1\frac{29}{64}$	1·4531	0·0023	1·4508	26	0·0492	0·03846	0·0117	1·5000	$1\frac{33}{64}$	1·5156	0·0156

Class "A."—Tapping drills are calculated to produce approximately 95 per cent. of full thread. Class "B," 87 per cent. Class "C," 75 per cent.

Class "A."—Clearing drills are approximately 1 per cent. larger than screw diameter. Class "B," $2\frac{1}{2}$ per cent. Class "C," 5 per cent.

If the calculated drill is not available refer to drill table for nearest size.

N.S. = Non Standard. When working to Class "A" or "B," hand tapping is usually adopted. For power tapping, use Class "C."

STANDARD BRASS THREAD 55° ANGLE

Class "C" (Medium Fit)

Screw Dia.	*Tapping Drill*	*Decimal*	*Tolerance*	*Clearing Drill*	*Decimal*	*Tolerance*
$\frac{1}{8}$	No. 45	0·0820	0·0062	No. 30	0·1285	0·0035
$\frac{3}{16}$	3·70 mm.	0·1457	0·0074	4·90 mm.	0·1929	0·0054
$\frac{1}{4}$	No. 4	0·2090	0·0082	Letter F	0·2570	0·0070
$\frac{5}{16}$	Letter I	0·2720	0·0087	8·20 mm.	0·3228	0·0103
$\frac{3}{8}$	Letter Q	0·3320	0·0062	9·80 mm.	0·3858	0·0108
$\frac{7}{16}$	Letter X	0·3970	0·0087	11·40 mm.	0·4488	0·0113
$\frac{1}{2}$	11·60 mm.	0·4567	0·0059	13·0 mm.	0·5118	0·0118
$\frac{5}{8}$	N.S.	0·5828	0·0070	$\frac{41}{64}$	0·6406	0·0156
$\frac{3}{4}$	18·0 mm.	0·7087	0·0079	19·50 mm.	0·7677	0·0177
$\frac{7}{8}$	N.S.	0·8328	0·0070	$\frac{57}{64}$	0·8906	0·0156
1 in.	N.S.	0·9578	0·0070	26·0 mm.	1·0236	0·0236
$1\frac{1}{8}$	27·50 mm.	1·0827	0·0069	$1\frac{5}{32}$	1·1563	0·0313
$1\frac{1}{4}$	N.S.	1·2078	0·0070	$1\frac{9}{32}$	1·2813	0·0313
$1\frac{1}{2}$	37·0 mm.	1·4567	0·0059	39·0 mm.	1·5354	0·0354

STANDARD BRASS THREAD 55° ANGLE

Class "C" (Free Fit)

Screw Dia.	*Tapping Drill*	*Decimal*	*Tolerance*	*Clearing Drill*	*Decimal*	*Tolerance*
$\frac{1}{8}$	2·20 mm.	0·0866	0·0108	3·30 mm.	0·1299	0·0049
$\frac{3}{16}$	No. 25	0·1495	0·0112	5·0 mm.	0·1969	0·0094
$\frac{1}{4}$	5·40 mm.	0·2126	0·0118	Letter G	0·2610	0·0110
$\frac{5}{16}$	7·0 mm.	0·2756	0·0123	$\frac{21}{64}$	0·3281	0·0156
$\frac{3}{8}$	8·60 mm.	0·3386	0·0128	10·0 mm.	0·3937	0·0187
$\frac{7}{16}$	10·20 mm.	0·4016	0·0133	$\frac{29}{64}$	0·4531	0·0156
$\frac{1}{2}$	11·80 mm.	0·4646	0·0138	$\frac{17}{32}$	0·5313	0·0313
$\frac{5}{8}$	15·0 mm.	0·5906	0·0148	$\frac{21}{32}$	0·6563	0·0313
$\frac{3}{4}$	N.S.	0·7128	0·0120	20·0 mm.	0·7874	0·0374
$\frac{7}{8}$	N.S.	0·8378	0·0120	$\frac{59}{64}$	0·9219	0·0469
1 in.	24·50 mm.	0·9646	0·0138	$1\frac{3}{64}$	1·0469	0·0469
$1\frac{1}{8}$	N.S.	1·0878	0·0120	30·0 mm.	1·1811	0·0561
$1\frac{1}{4}$	N.S.	1·2128	0·0120	$1\frac{5}{16}$	1·3125	0·0625
$1\frac{1}{2}$	N.S.	1·4628	0·0120	$1\frac{9}{16}$	1·5625	0·0625

Class "A."—Tapping drills are calculated to produce approximately 95 per cent. of full thread. Class "B," 87 per cent. Class "C," 75 per cent.

Class "A."—Clearing drills are approximately 1 per cent. larger than screw diameter. Class "B," $2\frac{1}{2}$ per cent. Class "C," 5 per cent.

If the calculated drill is not available refer to drill table for nearest size.

N.S. = Non Standard. When working to Class "A" or "B," hand tapping is usually adopted. For power tapping, use Class "C."

BRITISH STANDARD PIPE 55° ANGLE

Class "A" (Close Fit)

Pipe Dia. (inside)	*Tapping Drill*	*Decimal*	*Tolerance*	*Minor Dia.*	*T.P.I.*	*Double Depth of Thread*	*Pitch*	*B.S.I. Minor Dia. Tolerance*	*Pipe Dia. Outside*	*Major Dia.*	*Clearing Drill*	*Decimal*	*Tolerance*
$\frac{1}{8}$	Letter R	0 3390	0·002	0·337	28	0·0457	0·0357	0·0111	$\frac{13}{32}$	0·383	Letter W	0·3860	0·0030
$\frac{1}{4}$	$\frac{29}{64}$	0·4531	0 0021	0·451	19	0·0670	0·0526	0·0175	$\frac{17}{32}$	0·518	N.S.	0·5230	0·0050
$\frac{3}{8}$	$\frac{19}{32}$	0·5938	0·0048	0·589	19	0·0670	0·0526	0·0175	$\frac{11}{16}$	0·656	N.S.	0·6625	0·0065
$\frac{1}{2}$	N.S.	0·7385	0·0045	0·734	14	0·0910	0 0714	0 0213	$\frac{27}{32}$	0·825	N.S.	0·8330	0·0080
$\frac{5}{8}$	N.S.	0·8155	0·0045	0·811	14	0 0910	0·0714	0·0213	$\frac{15}{16}$	0·902	N.S.	0·9110	0·0090
$\frac{3}{4}$	N.S.	0·9545	0·0045	0·950	14	0·0910	0·0714	0 0213	$1\frac{1}{16}$	1·041	$1\frac{3}{64}$	1·0469	0·0059
$\frac{7}{8}$	28·0 mm.	1·1024	0·0044	1·098	14	0·0910	0·0714	0·0213	$1\frac{7}{32}$	1·189	$1\frac{13}{64}$	1·2031	0·0141
1	30·50 mm.	1·2008	0·0078	1·193	11	0·1164	0·0909	0·0252	$1\frac{11}{32}$	1·309	33·50 mm.	1·3189	0·0099
$1\frac{1}{4}$	N.S.	1·5400	0·0060	1·534	11	0·1164	0·0909	0·0252	$1\frac{11}{16}$	1·650	N.S	1·6665	0·0165
$1\frac{1}{2}$	45·0 mm.	1·7717	0·0057	1·766	11	0·1164	0·0909	0·0252	$1\frac{29}{32}$	1·882	$1\frac{29}{32}$	1·9063	0·0213
$1\frac{3}{4}$	51·0 mm.	2·0079	0·0079	2·000	11	0·1164	0·0909	0·0252	$2\frac{9}{32}$	2·116	$2\frac{9}{64}$	2·1406	0·0246
2	N.S.	2·2370	0·0060	2·231	11	0·1164	0·0909	0·0252	$2\frac{3}{8}$	2·347	$2\frac{3}{8}$	2·3750	0·0280
$2\frac{1}{4}$	63·0 mm.	2·4803	0·0092	2·471	11	0·1164	0·0909	0·0252	$2\frac{5}{8}$	2·587	$2\frac{39}{64}$	2·6094	0·0224
$2\frac{1}{2}$	N.S.	2·850	0·0060	2·844	11	0·1164	0·0909	0·0252	3	2·960	$2\frac{63}{64}$	2·9844	0·0244
$2\frac{3}{4}$	N.S.	3·1000	0·0060	3·094	11	0·1164	0·0909	0·0252	$3\frac{1}{4}$	3·210	$3\frac{15}{64}$	3·2344	0·0244
3	N.S.	3·3500	0·0060	3·344	11	0·1164	0·0909	0·0252	$3\frac{1}{2}$	3·460	$3\frac{1}{2}$	3·5000	0·0400
$3\frac{1}{4}$	$3\frac{19}{32}$	3·5938	0·0098	3·584	11	0·1164	0·0909	0 0252	$3\frac{3}{4}$	3·700	$3\frac{47}{64}$	3·7344	0·0344
$3\frac{1}{2}$	$3\frac{27}{32}$	3·8438	0·0098	3·834	11	0·1164	0·0909	0·0252	4	3·950	$3\frac{63}{64}$	3·9844	0·0311
$3\frac{3}{4}$	$4\frac{3}{32}$	4·0938	0·0098	4·084	11	0·1164	0·0909	0·0252	$4\frac{1}{4}$	4·200	$4\frac{15}{64}$	4 2344	0·0344
4	$4\frac{11}{32}$	4·3438	0·0098	4·334	11	0·1164	0·0909	0·0252	$4\frac{1}{2}$	4·450	$4\frac{1}{2}$	4·5000	0·0500

BRITISH STANDARD PIPE 55° ANGLE
Class "B" (Medium Fit)

Pipe Dia. (inside)	*Tapping Drill*	*Decimal*	*Tolerance*	*Clearing Drill*	*Decimal*	*Tolerance*
$\frac{1}{8}$	8·70 mm.	0·3425	0·0055	10·0 mm.	0·3937	0·0107
$\frac{1}{4}$	11·70 mm.	0·4606	0·0096	$\frac{17}{32}$	0·5313	0·0133
$\frac{3}{8}$	N.S.	0·6010	0·0120	$\frac{43}{64}$	0·6719	0·0159
$\frac{1}{2}$	19·0 mm.	0·7480	0·0140	$\frac{27}{32}$	0·8438	0·0188
$\frac{5}{8}$	21·0 mm.	0·8268	0·0158	$\frac{59}{64}$	0·9219	0·0199
$\frac{3}{4}$	24·50 mm.	0·9646	0·0146	$1\frac{1}{16}$	1·0625	0·0215
$\frac{7}{8}$	$1\frac{7}{64}$	1·1094	0·0114	$1\frac{7}{32}$	1·2188	0·0298
1	$1\frac{13}{64}$	1·2031	0·0101	$1\frac{11}{32}$	1·3438	0·0348
$1\frac{1}{4}$	$1\frac{35}{64}$	1·5469	0·0129	$1\frac{11}{16}$	1·6875	0·0375
$1\frac{1}{2}$	$1\frac{25}{32}$	1·7813	0·0153	$1\frac{59}{64}$	1·9219	0·0399
$1\frac{3}{4}$	$2\frac{1}{64}$	2·0156	0·0156	$2\frac{5}{32}$	2·1563	0·0403
2	57·0 mm.	2·2441	0·0131	$2\frac{25}{64}$	2·3906	0·0436
$2\frac{1}{4}$	$2\frac{31}{64}$	2·4844	0·0134	$2\frac{41}{64}$	2·6406	0·0536
$2\frac{1}{2}$	$2\frac{55}{64}$	2·8594	0·0154	$3\frac{1}{64}$	3·0156	0·0556
$2\frac{3}{4}$	$3\frac{7}{64}$	3·1094	0·0154	$3\frac{17}{64}$	3·2656	0·0556
3	$3\frac{23}{64}$	3·3594	0·0154	$3\frac{33}{64}$	3·5156	0·0556
$3\frac{1}{4}$	N.S.	3·5990	0·0150	$3\frac{49}{64}$	3·7656	0·0656
$3\frac{1}{2}$	N.S.	3·8490	0·0150	$4\frac{1}{64}$	4·0156	0·0656
$3\frac{3}{4}$	N.S.	4·0990	0·0150	$4\frac{9}{32}$	4·2813	0·0813
4	N.S.	4·3490	0·0150	$4\frac{17}{32}$	4·5313	0·0813

BRITISH STANDARD PIPE 55° ANGLE
Class "C" (Free Fit)

Pipe Dia. (inside)	*Tapping Drill*	*Decimal*	*Tolerance*	*Clearing Drill*	*Decimal*	*Tolerance*
$\frac{1}{8}$	Letter S	0·3480	0·0110	10·20 mm.	0·4016	0·0186
$\frac{1}{4}$	11·80 mm.	0·4646	0·0136	$\frac{35}{64}$	0·5469	0·0289
$\frac{3}{8}$	$\frac{39}{64}$	0·6094	0·0204	$\frac{11}{16}$	0·6875	0·0315
$\frac{1}{2}$	$\frac{3}{4}$	0·7500	0·0160	$\frac{55}{64}$	0·8594	0·0344
$\frac{5}{8}$	$\frac{53}{64}$	0·8281	0·0171	24·0 mm.	0·9449	0·0429
$\frac{3}{4}$	$\frac{31}{32}$	0·9688	0·0188	$1\frac{3}{32}$	1·0938	0·0528
$\frac{7}{8}$	28·50 mm.	1·1221	0·0241	31·50 mm.	1·2402	0·0512
1	$1\frac{7}{32}$	1·2188	0·0258	$1\frac{23}{64}$	1·3594	0·0504
$1\frac{1}{4}$	$1\frac{9}{16}$	1·5625	0·0285	44·0 mm.	1·7323	0·0823
$1\frac{1}{2}$	$1\frac{51}{64}$	1·7969	0·0309	50·0 mm.	1·9685	0·0865
$1\frac{3}{4}$	$2\frac{1}{32}$	2·0313	0·0313	$2\frac{7}{32}$	2·2188	0·1028
2	$2\frac{17}{64}$	2·2656	0·0346	62·50 mm.	2·4606	0·1136
$2\frac{1}{4}$	$2\frac{1}{2}$	2·5000	0·0290	$2\frac{45}{64}$	2·7031	0·1161
$2\frac{1}{2}$	$2\frac{7}{8}$	2·8750	0·0310	$3\frac{3}{32}$	3·0938	0·1338
$2\frac{3}{4}$	$3\frac{1}{8}$	3·1250	0·0310	$3\frac{23}{64}$	3·3594	0·1494
3	$3\frac{3}{8}$	3·3750	0·0310	$3\frac{19}{32}$	3·5878	0·1278
$3\frac{1}{4}$	$3\frac{39}{64}$	3·6094	0·0254	$3\frac{7}{8}$	3·8750	0·1750
$3\frac{1}{2}$	$3\frac{55}{64}$	3·8594	0·0254	$4\frac{9}{64}$	4·1406	0·1906
$3\frac{3}{4}$	$4\frac{7}{64}$	4·1094	0·0254	$4\frac{25}{64}$	4·3906	0·1906
4	$4\frac{23}{64}$	4·3594	0·0254	$4\frac{41}{64}$	4·6406	0·1906

AMERICAN NATIONAL THREAD

Diameter of Screw at Top of Thread	Threads per inch	Diameter at Root of Thread	Width of Flat, Top and Bottom
$\frac{1}{4}$	20	·185	·0063
$\frac{5}{16}$	18	·2403	·0069
$\frac{3}{8}$	16	·2936	·0078
$\frac{7}{16}$	14	·3447	·0089
$\frac{1}{2}$	13	·4001	·0096
$\frac{9}{16}$	12	·4542	·0104
$\frac{5}{8}$	11	·5069	·0114
$\frac{3}{4}$	10	·6201	·0125
$\frac{7}{8}$	9	·7307	·0139
1	8	·8376	·0156
$1\frac{1}{8}$	7	·9394	·0179
$1\frac{1}{4}$	7	1·0644	·0179
$1\frac{3}{8}$	6	1·1585	·0208
$1\frac{1}{2}$	6	1·2835	·0208
$1\frac{5}{8}$	$5\frac{1}{2}$	1·3888	·0227
$1\frac{3}{4}$	5	1·4902	·0250
$1\frac{7}{8}$	5	1·6152	·0250
2	$4\frac{1}{2}$	1·7113	·0278
$2\frac{1}{4}$	$4\frac{1}{2}$	1·9613	·0278
$2\frac{1}{2}$	4	2·1752	·0313
$2\frac{3}{4}$	4	2·4252	·0313
3	$3\frac{1}{2}$	2·6288	·0357
$3\frac{1}{4}$	$3\frac{1}{2}$	2·8788	·0357
$3\frac{1}{2}$	$3\frac{1}{4}$	3·1003	·0385
$3\frac{3}{4}$	3	3·3170	·0417
4	3	3·5670	·0417
$4\frac{1}{4}$	$2\frac{7}{8}$	3·7982	·0435
$4\frac{1}{2}$	$2\frac{3}{4}$	4·0276	·0455
$4\frac{3}{4}$	$2\frac{5}{8}$	4·2551	·0476
5	$2\frac{1}{2}$	4·4804	·0500
$5\frac{1}{4}$	$2\frac{1}{2}$	4·7304	·0500
$5\frac{1}{2}$	$2\frac{3}{8}$	4·9530	·0526
$5\frac{3}{4}$	$2\frac{3}{8}$	5·2030	·0526
6	$2\frac{1}{4}$	5·4226	·0556

SYSTÈME INTERNATIONALE (METRIC) THREADS (S.I.)

Nominal Diameter	Pitch	Effective Diameter	Plug or Screw		Ring or Nut	
			Core Diameter	Core Section	Thread Diameter	Core Diameter
mm.	mm.	mm.	mm.	sq. mm.	mm.	mm.
1	0·25	0·838	0·65	0·33	1·03	0·68
1·2	0·25	1·038	0·85	0·57	1·23	0·88
1·4	0·3	1·205	0·98	0·75	1·43	1·01
1·7	0·35	1·473	1·21	1·15	1·74	1·25
2	0·4	1·740	1·44	1·62	2·04	1·48
2·3	0·4	2·040	1·74	2·37	2·34	1·78
2·6	0·45	2·308	1·97	3·04	2·65	2·02
3	0·5	2·675	2·30	4·14	3·05	2·35
3·5	0·6	3·110	2·66	5·54	3·56	2·72
4	0·7	3·545	3·01	7·14	4·08	3·09
4·5	0·75	4·013	3·44	9·32	4·58	3·53
5	0·8	4·480	3·87	11·79	5·09	3·96
6	1	5·350	4·59	16·57	6·11	4·70
7	1	6·350	5·59	24·57	7·11	5·70
8	1·25	7·188	6·24	30·59	8·14	6·38
9	1·25	8·188	7·24	41·18	9·14	7·38
10	1·5	9·026	7·89	48·88	10·16	8·05
12	1·75	10·863	9·54	71·44	12·19	9·73
14	2	12·701	11·19	98·26	14·22	11·40
16	2	14·701	13·19	137	16·22	13·40
18	2·5	16·376	14·48	165	18·27	14·75
20	2·5	18·376	16·48	213	20·27	16·75
22	2·5	20·376	18·48	268	22·27	18·75
24	3	22·051	19·78	307	24·32	20·10
27	3	25·051	22·78	407	27·32	23·10
30	3·5	27·727	25·07	494	30·38	25·45
33	3·5	30·727	28·07	619	33·38	28·45
36	4	33·402	30·37	724	36·43	30·80
39	4	36·402	33·37	875	39·43	33·80
42	4·5	39·077	35·67	999	42·49	36·15
45	4·5	42·077	38·67	1174	45·49	39·15
48	5	44·752	40·96	1318	48·54	41·50
52	5	48·752	44·96	1588	52·54	45·50
56	5·5	52·428	48·26	1829	56·60	48·86
60	5·5	56·428	52·26	2145	60·60	52·86
64	6	60·103	55·56	2424	64·65	56·21
68	6	64·103	59·56	2786	68·65	60·21
72	6	68·103	63·56	3173	72·65	64·21
76	6	72·103	67·56	3584	76·65	68·21
80	6	76·103	71·56	4021	80·65	72·21

BRITISH STANDARD CYCLE THREADS

Formerly Cycle Engineers' Institute (C.E.I.) (STD.)

Size Imp. Wire Gauge	Diameter	Threads per inch	Pitch	Core Diameter	Tapping Size Drill
	in.		in.	in.	
17	·056	62	·0161	·0388	61
16	·064	62	·0161	·0468	56
15	·072	62	·0161	·0548	54
14	·080	62	·0161	·0628	$\frac{1}{16}$
13	·092	56	·0178	·0730	49
12	·104	44	·0227	·0798	47
$\frac{1}{8}$ inches	·125	40	·025	·0984	$2\frac{1}{2}$ mm.
·154 ,,	·154	40	·025	·1274	30
·175 ,,	·175	32	·03125	·1417	27
$\frac{3}{16}$,,	·1875	32	·03125	·1542	23
$\frac{1}{4}$,,	·250	26	·0384	·2090	4
·266 ,,	·266	26	·0384	·2250	1
·281 ,,	·281	26	·0384	·2400	C
$\frac{5}{16}$,,	·3125	26	·0384	·2715	1
$\frac{3}{8}$,,	·375	26	·0384	·3340	$8\frac{1}{2}$ mm.
$\frac{9}{16}$,,	·5625	20	·0500	·5092	13 ,,
1 ,,	1·000	26	·0384	·9590	$24\frac{1}{2}$,,
1·29 ,,	1·29	24	·04167	1·2456	$1\frac{1}{4}$
1·37 ,,	1·370	24	·04167	1·3256	$1\frac{21}{64}$
$1\frac{7}{16}$,,	1·4375	24	·04167	1·3931	$35\frac{1}{2}$ mm.
$1\frac{1}{2}$,,	1·500	24	·04167	1·4556	37 ,,

Angle of thread = 60° included.
Theoretical depth = ·866 P.
Actual depth = ·5327 P.
Rounding at crest and root = ·166 P.
Radius at crest and root = ·166 P.

ACME STANDARD SCREW THREAD

$$\text{Width of point of tool for screw or tap thread} = \frac{\cdot3707}{\text{threads per in.}} - \cdot0052$$

$$p = \text{pitch} = \frac{1}{\text{No. threads per inch}}$$

Formula $d = \text{depth} = \tfrac{1}{2}p \times \cdot010$

$$f = \text{flat on top of thread} = p \times \cdot3707$$

$$f' = \text{“ on bottom ”} = p \times \cdot3707 - \cdot0052$$

Pitch	No. of Threads per in.	Depth of Thread	Width at Top of Thread	Width at Bottom of Thread	Space at Top of Thread	Thickness at Root of Thread
2	$\frac{1}{2}$	1·010	·7414	·7362	1·2586	1·2637
$1\frac{7}{8}$	$\frac{8}{15}$	·09475	·6950	·6897	1·1799	1·1850
$1\frac{3}{4}$	$\frac{4}{7}$	0·8850	·6487	·6435	1·1012	1·1064
$1\frac{5}{8}$	$\frac{8}{13}$	0·8225	·6025	·5973	1·0226	1·0277
$1\frac{1}{2}$	$\frac{2}{3}$	0·7600	·5560	·5508	0·9439	0·9491
$1\frac{7}{16}$	$\frac{16}{23}$	0·7287	·5329	·5277	0·9046	0·9097
$1\frac{3}{8}$	$\frac{8}{11}$	0·6975	·5097	·5045	0·8652	0·8704
$1\frac{5}{16}$	$\frac{16}{21}$	0·6662	·4865	·4813	0·8259	0·8311
$1\frac{1}{4}$	$\frac{4}{5}$	0·635	·4633	·4581	0·7866	0·7918
$1\frac{3}{16}$	$\frac{16}{19}$	0·6037	·4402	·4350	0·7472	0·7525
$1\frac{1}{8}$	$\frac{8}{9}$	0·5725	·4170	·4118	0·7079	0·7131
$1\frac{1}{16}$	$\frac{16}{17}$	0·5412	·3938	·3886	0·6686	0·6739
1	1	0·510	·3707	·3655	0·6293	0·6345
$\frac{15}{16}$	$1\frac{1}{15}$	0·4787	·3476	·3424	0·5898	0·5950
$\frac{7}{8}$	$1\frac{1}{7}$	0·4475	·3243	·3191	0·5506	0·5558
$\frac{13}{16}$	$1\frac{3}{13}$	0·4162	·3012	·2960	0·5112	0·5164
$\frac{3}{4}$	$1\frac{1}{3}$	0·385	·2780	·2728	0·4720	0·4772
$\frac{11}{16}$	$1\frac{5}{11}$	0·3537	·2548	·2496	0·4327	0·4379
$\frac{2}{3}$	$1\frac{1}{2}$	0·3433	·2471	·2419	0·4194	0·4246
$\frac{5}{8}$	$1\frac{3}{5}$	0·3225	·2316	·2264	0·3934	0·3986
$\frac{9}{16}$	$1\frac{7}{9}$	0·2912	·2085	·2033	0·3539	0·3591
$\frac{1}{2}$	2	0·260	·1853	·1801	0·3147	0·3199
$\frac{7}{16}$	$2\frac{2}{7}$	0·2287	·1622	·1570	0·2752	0·2804
$\frac{2}{5}$	$2\frac{1}{2}$	0·210	·1482	·1430	0·2518	0·2570
$\frac{3}{8}$	$2\frac{2}{3}$	0·1975	·1390	·1338	0·2359	0·2411
$\frac{1}{3}$	3	0·1766	·1235	·1183	0·2098	0·2150
$\frac{5}{16}$	$3\frac{1}{5}$	0·1662	·1158	·1106	0·1966	0·2018
$\frac{2}{7}$	$3\frac{1}{2}$	0·1528	·1059	·1007	0·1797	0·1849
$\frac{1}{4}$	4	0·1350	·0927	·0875	0·1573	0·1625
$\frac{2}{9}$	$4\frac{1}{2}$	0·1211	·0824	·0772	0·1398	0·1450
$\frac{1}{5}$	5	0·110	·0741	·0689	0·1259	0·1311
$\frac{3}{16}$	$5\frac{1}{3}$	0·1037	·0695	·0643	0·1179	0·1232
$\frac{1}{6}$	6	0·0933	·0617	·0565	0·1049	0·1101
$\frac{1}{7}$	7	0·0814	·0530	·0478	0·0899	0·0951
$\frac{1}{8}$	8	0·0725	·0463	·0411	0·0787	0·0839
$\frac{1}{9}$	9	0·0655	·0413	·0361	0·0699	0·0751
$\frac{1}{10}$	10	0·060	·0371	·0319	0·0629	0·0681
$\frac{1}{16}$	16	0·0412	·0232	·0180	0·0392	0 0444

LOEWENHERZ THREADS

Diameter	Approx. Diameter	Pitch	Core Diameter	Effective Diameter
mm.	in.	mm.	mm.	mm.
1·0	·0394	·25	·625	·812
1·2	·0472	·25	·825	1·017
1·4	·0551	·30	·950	1·175
1·7	·0669	·35	1·175	1·437
2·0	·0787	·40	1·400	1·700
2·3	·0905	·40	1·700	2·000
2·6	·1024	·45	1·925	2·260
3·0	·1181	·50	2·250	2·620
3·5	·1378	·60	2·600	3·050
4·0	·1575	·70	2·950	3·470
4·5	·1772	·75	3·375	3·937
5·0	·1969	·80	3·800	4·400
5·5	·2165	·90	4·150	4·825
6·0	·2362	1·0	4·500	5·750
7·0	·2756	1·10	5·350	6·175
8·0	·3150	1·20	6·200	7·100
9·0	·3543	1·30	7·050	8·025
10	·3937	1·40	7·900	8·950
12	·4724	1·60	9·600	10·800
14	·5512	1·80	11·300	12·650
16	·6299	2·00	13·000	14·500
18	·7087	2·20	14·700	16·350

Theoretical depth = Pitch.
Actual depth = ·75 P.
Depth of flat = ·125 P.

MODEL SCREW THREADS

$\frac{1}{4}$ in. and less	40 threads per inch.
$\frac{5}{16}$ in.	32 ,, ,, ,,
$\frac{3}{8}$ in.	32 ,, ,, ,,
$\frac{7}{16}$ in.	26 ,, ,, ,,
$\frac{1}{2}$ in.	26 ,, ,, ,,

Model threads are cut to Whitworth Form.

ROYAL MICROSCOPICAL SOCIETY SCREW THREAD
(Whitworth Form)

Screw Thread for Objective

Pitch 36 threads per inch=0·02778 in. approximately (=0·7056 mm.). Length of thread 0·125 in. (3·175 mm.).

	Maximum		Minimum	
	in.	mm.	in.	mm.
Full diameter . .	0·7982	20·274	0·7952	20·198
Effective diameter .	0·7804	19·822	—	—
Core diameter . .	0·7626	19·370	—	—

Note.—*The objective is to screw home properly to shoulder. Plain fitting (pilot) above the thread of the objective: diameter is not to exceed* 0·7626 *inches* (19·370 *mm.*). *Length of pilot* 0·1 *inches* (2·54 *mm.*).

Screw Thread for Nose Piece

Form pitch as for the objective screw.
Length of thread not to be less than 0·125 in. (3·175 mm.).

	Minimum		Maximum	
	in.	mm.	in.	mm.
Full diameter . .	0·8	20·320	—	—
Effective diameter .	0·7822	19·868	—	—
Core diameter . .	0·7644	19·416	0·7674	19·492

ROYAL PHOTOGRAPHIC SOCIETY SCREW THREAD
(Whitworth Form)

Diameter (inches)	Threads per in.	Core Diameter	Diameter (inches)	Threads per in.	Core Diameter
1	24	·9466	2	24	1·9466
1¼	24	1·1966	2¼	24	2·1966
1⅜	24	1·3216	2½	24	2·4466
1½	24	1·4466	3	24	2·9466
1⅝	24	1·5716	3½	12	3·3933
1¾	24	1·6966	4	12	3·8933
1⅞	24	1·8216	5	12	4·8933

For screws under 1 in. diameter adopt the Royal Microscopical Society's Standard. Stand fittings are $\frac{3}{16}$ in., ¼ in., $\frac{5}{16}$ in. or ⅜ in. diameter (Whitworth Standard).

WALTHAM WATCH SCREW TAPS

No. of Tap	No. of Threads to an inch	Diameter of Thread on Screws		Diameter of Drill	
		in.	mm.	in.	mm.
1	110	0·05906	1·50	0·05197	1·32
3	110	0·04724	1·20	0·04016	1·02
5	120	0·04331	1·10	0·03741	0·95
7	140	0·03937	1·00	0·03347	0·85
9	160	0·03661	0·93	0·02796	0·71
11	170	0·05276	1·34	0·04803	1·22
13	180	0·03937	1·00	0·03347	0·85
15	180	0·03268	0·83	0·02796	0·71
17	200	0·02560	0·65	0·02126	0·54
19	220	0·02166	0·55	0·01772	0·45
21	240	0·01772	0·45	0·01339	0·34
23	254	0·01379	0·35	0·01064	0·27

WATCH PENDANT TAPS

Size	Diameter of Tap		Threads per inch	Diameter of Drill	
	in.	mm.		in.	mm.
18	·236	5·90	50	·211	5·28
16	·200	5·00	60	·180	4·50
12-6	·176	4·40	66	·158	3·95
0	·156	3·90	66	·138	3·45
5/0	·128	3·20	80	·114	2·85
10/0	·103	2·58	90	·086	2·15

WATCH CROWN TAPS

Size	Diameter of Tap		Threads per inch	Diameter of Drill	
	in.	mm.		in.	mm.
18	·091	2·28	60	·071	1·78
16	·077	1·93	72	·063	1·58
12-6-0	·061	1·53	80	·048	1·20
5/0-10/0	·048	1·20	110	·038	0·95

ELGIN WATCH SCREW TAPS

(L = left-hand)

Diameter of Tap		Threads per inch	Diameter of Drill	
in.	mm.		in.	mm.
·0132	·33	360	·0112	·28
·0148	·37	320	·0120	·30
·0168	·42	260	·0132	·33
·0208	·52	220	·0168	·42
·0228	·57	260	·0188	·47
·0248	·62	220	·0200	·50
·0268	·67	180	·0220	·55
·0288	·72	220	·0248	·62
·0308	·77	180	·0248	·62
·0308	·77	220	·0268	·67
·0368	·92	140	·0280	·70
·0368	·92	220	·0268	·67
·0408	1·02	120L	·0300	·75
·0408	1·02	200	·0348	·87
·0428	1·07	120	·0328	·82
·0448	1·12	110	·0340	·85
·0468	1·17	110	·0348	·87
·0488	1·22	140	·0400	1·00
·0488	1·22	200	·0436	1·09
·0508	1·27	110L	·0388	1·97
·0548	1·37	180	·0488	1·22
·0608	1·52	110	·0488	1·22
·0608	1·52	110L	·0488	1·22
·0708	1·77	180L	·0648	1·62
·0768	1·92	110L	·0708	1·77
·0772	1·93	80L	·0612	1·53
·0892	2·23	80L	·0712	1·78

TWIST DRILL GAUGE SIZES

No. Drill	Decimal Size	No. Drill	Decimal Size	No. Drill	Decimal Size
1	·2280	21	·1590	41	·0960
2	·2210	22	·1570	42	·0935
3	·2130	23	·1540	43	·0890
4	·2090	24	·1520	44	·0860
5	·2055	25	·1495	45	·0820
6	·2040	26	·1470	46	·0810
7	·2010	27	·1440	47	·0785
8	·1990	28	·1405	48	·0760
9	·1960	29	·1360	49	·0730
10	·1935	30	·1285	50	·0700
11	·1910	31	·1200	51	·0670
12	·1890	32	·1160	52	·0635
13	·1850	33	·1130	53	·0595
14	·1820	34	·1110	54	·0550
15	·1800	35	·1100	55	·0520
16	·1770	36	·1065	56	·0465
17	·1730	37	·1040	57	·0430
18	·1695	38	·1015	58	·0420
19	·1660	39	·0995	59	·0410
20	·1610	40	·0980	60	·0400

SWISS SCREW THREAD
(Thury)

No.	Dimensions in millimetres		Ratio of Successive Diam.	Approx. Diam. in inches	Threads per inch	No.	Dimensions in millimetres		Ratio of Successive Diam.	Approx. Diam. in inches	Threads per inch
	Pitch	Outside Diam.					Pitch	Outside Diam.			
25	0·0718	0·254	0·879	0·0100	353·70	2	0·810	4·66	0·881	0·1835	31·35
24	0·0798	0·289	0·881	0·0114	318·30	1	0·900	5·29	0·882	0·2083	28·22
23	0·0886	0·328	0·882	0·0129	286·65	0	1·000	6·00	0·881	0·2362	25·40
22	0·0985	0·372	0·872	0·0146	255·32	−1	1·11	6·81	0·881	0·2681	22·85
21	0·109	0·426	0·889	0·0168	233·02	−2	1·23	7·73	0·881	0·3043	20·65
20	0·122	0·479	0·882	0·0189	208·19	−3	1·37	8·77	0·881	0·3453	18·54
19	0·135	0·543	0·882	0·0214	188·40	−4	1·52	9·95	0·880	0·3917	16·73
18	0·150	0·616	0·881	0·0243	169·33	−5	1·69	11·3	0·883	0·4449	15·02
17	0·167	0·699	0·880	0·0275	152·32	−6	1·88	12·8	0·883	0·5039	13·48
16	0·185	0·794	0·881	0·0313	137·29	−7	2·09	14·5	0·879	0·5709	12·15
15	0·206	0·901	0·883	0·0355	123·30	−8	2·32	16·5	0·882	0·6496	10·94
14	0·229	1·102	0·879	0·0402	110·91	−9	2·58	18·7	0·882	0·7362	9·84
13	0·254	1·16	0·879	0·0457	100·00	−10	2·87	21·2	0·880	0·8346	8·85
12	0·282	1·32	0·886	0·0520	90·07	−11	3·19	24·1	0·880	0·9488	7·97
11	0·314	1·49	0·909	0·0587	80·89	−12	3·54	27·4	0·884	1·0787	7·17
10	0·349	1·64	0·854	0·0646	72·77	−13	3·93	31·0	0·881	1·2048	6·46
9	0·387	1·92	0·881	0·0756	65·63	−14	4·37	35·2	0·880	1·3858	5·81
8	0·430	2·18	0·879	0·0858	59·06	−15	4·86	40·0	0·881	1·5748	5·22
7	0·478	2·48	0·883	0·0976	53·13	−16	5·40	45·4	0·882	1·7874	4·84
6	0·531	2·81	0·881	0·1106	47·80	−17	6·00	51·5	0·882	2·0276	4·23
5	0·590	3·19	0·881	0·1256	43·05	−18	6·66	58·4	0·881	2·2992	3·82
4	0·656	3·62	0·881	0·1425	38·71	−19	7·40	66·3	0·882	2·6103	3·43
3	0·729	4·11	0·882	0·1618	34·84	−20	8·23	75·2	0·882	2·9607	3·08

AMERICAN NATIONAL FINE THREAD SERIES
THREAD ELEMENTS AND TAP DRILL SIZES

Numbered and Fractional Sizes	Number of Threads per inch	Basic Diameters: Major (Outside) Diameter inches	Basic Diameters: Pitch Diameter inches	Basic Diameters: Minor (Core) Diameter inches	Metric Equivalent of Major Diameter millimetres	Pitch inches	Depth of Thread inches	Tap Drills: Tap Drill to Produce Approx. 75 % Full Thread	Tap Drills: Decimal Equivalent of Tap Drill inches
0	80	0·0600	0·0519	0·0438	1·524	0·01250	0·00812	1·20 mm.	0·0472
1	72	0·0730	0·0640	0·0550	1·854	0·01388	0·00902	53	0·0595
2	64	0·0860	0·0759	0·0657	2·184	0·01562	0·01014	1·80 mm.	0·0709
3	56	0·0990	0·0874	0·0758	2·515	0·01785	0·01160	45	0·0820
4	48	0·1120	0·0985	0·0849	2·845	0·02083	0·01353	2·30 mm.	0·0905
5	44	0·1250	0·1102	0·0955	3·175	0·02272	0·01476	2·60 mm.	0·1024
6	40	0·1380	0·1218	0·1055	3·506	0·02500	0·01624	33	0·1130
8	36	0·1640	0·1460	0·1279	4·166	0·02777	0·01804	29	0·1360
10	32	0·1900	0·1697	0·1494	4·826	0·03125	0·02030	21	0·1590
12	28	0·2160	0·1928	0·1696	5·486	0·03571	0·02319	4·60 mm.	0·1811
$\frac{1}{4}$	28	0·2500	0·2268	0·2036	6·350	0·03571	0·02319	5·50 mm.	0·2165
$\frac{5}{16}$	24	0·3125	0·2854	0·2584	7·938	0·04166	0·02706	I	0·2720
$\frac{3}{8}$	24	0·3750	0·3479	0·3209	9·525	0·04166	0·02706	8·50 mm.	0·3346
$\frac{7}{16}$	20	0·4375	0·4050	0·3725	11·113	0·05000	0·03248	9·90 mm.	0·3898
$\frac{1}{2}$	20	0·5000	0·4675	0·4350	12·700	0·05000	0·03248	11·5 mm.	0·4527
$\frac{9}{16}$	18	0·5625	0·5264	0·4903	14·288	0·05555	0·03608	13·0 mm.	0·5118
$\frac{5}{8}$	18	0·6250	0·5889	0·5528	15·875	0·05555	0·03608	14·5 mm.	0·5709
$\frac{3}{4}$	16	0·7500	0·7094	0·6688	19·050	0·06250	0·04060	17·5 mm.	0·6890
$\frac{7}{8}$	14	0·8750	0·8286	0·7822	22·225	0·07142	0·04640	20·5 mm.	0·8071
1	14	1·0000	0·9536	0·9072	25·400	0·07142	0·04640	* $\frac{59}{64}$	0·9218
$1\frac{1}{8}$	12	1·1250	1·0709	1·0167	28·575	0·08333	0·05413	26·5 mm.	1·0433
$1\frac{1}{4}$	12	1·2500	1·1959	1·1417	31·750	0·08333	0·05413	$1\frac{11}{64}$	1·1719
$1\frac{1}{2}$	12	1·5000	1·4459	1·3917	38·100	0·08333	0·05413	36·0 mm.	1·4173
$1\frac{3}{4}$	12	1·7500	1·6959	1·6417	44·450	0·08333	0·05413	$1\frac{43}{64}$	1·6718
2	12	2·0000	1·9459	1·8917	50·800	0·08333	0·05413	$1\frac{59}{64}$	1·9218
$2\frac{1}{4}$	12	2·2500	2·1959	2·1417	57·150	0·08333	0·05413	$2\frac{11}{64}$	2·1718
$2\frac{1}{2}$	12	2·5000	2·4459	2·3917	63·500	0·08333	0·05413	61·5 mm.	2·4212
$2\frac{3}{4}$	12	2·7500	2·6959	2·6417	69·850	0·08333	0·05413	$2\frac{43}{64}$	2·6718
3	10	3·0000	2·9350	2·8701	76·200	0·10000	0·06495	$2\frac{58}{64}$	2·9063

* Approximately 83 % Full Thread.

AMERICAN NATIONAL COARSE-THREAD SERIES

THREAD ELEMENTS AND TAP DRILL SIZES

Numbered and Fractional Sizes	Number of Threads per inch	Basic Diameters: Major (Outside) Diameter inches	Basic Diameters: Pitch Diameter inches	Basic Diameters: Minor (Core) Diameter inches	Metric Equivalent of Major Diameter millimetres	Pitch inches	Depth of Thread inches	Tap Drills: Tap Drill to Produce Approx. 75 % Full Thread	Tap Drills: Decimal Equivalent of Tap Drill inches
1	64	0·0730	0·0629	0·0527	1·854	0·01562	0·0101	1·45 mm.	0·0571
2	56	0·0860	0·0744	0·0628	2·184	0·01785	0·0116	1·75 mm	0·0689
3	48	0·0990	0·0855	0·0719	2·515	0·02083	0·0135	2·00 mm.	0·0787
4	40	0·1120	0·0958	0·0795	2·845	0·02500	0·0162	2·20 mm.	0·0866
5	40	0·1250	0·1088	0·0925	3·175	0·02500	0·0162	39	0·0995
6	32	0·1380	0·1177	0·0974	3·505	0·03125	0·0203	36	0·1065
8	32	0·1640	0·1437	0·1234	4·166	0·03125	0·0203	3·40 mm.	0·1339
10	24	0·1900	0·1629	0·1359	4·826	0·04166	0 0271	25	0·1495
12	24	0·2160	0·1889	0·1619	5·486	0·04166	0·0271	4·40 mm.	0·1732
$\frac{1}{4}$	20	0·2500	0·2175	0·1850	6·350	0·05000	0·0325	7	0·2010
$\frac{5}{16}$	18	0·3125	0·2764	0·2403	7·938	0·05555	0·0361	F	0·2570
$\frac{3}{8}$	16	0·3750	0·3344	0·2938	9·525	0·06250	0·0406	$\frac{5}{16}$	0·3125
$\frac{7}{16}$	14	0·4375	0·3911	0·3447	11·113	0·07142	0·0464	U	0·3680
$\frac{1}{2}$	13	0·5000	0·4500	0·4001	12·700	0·07692	0·0500	$\frac{27}{64}$	0·4219
$\frac{9}{16}$	12	0·5625	0·5084	0·4542	14·288	0·08333	0·0541	$\frac{31}{64}$	0·4844
$\frac{5}{8}$	11	0·6250	0·5660	0·5069	15·875	0·09090	0·0590	* $\frac{17}{32}$	0·5312
$\frac{3}{4}$	10	0·7500	0·6850	0·6201	19·050	0·10000	0·0650	16·5 mm.	0·6496
$\frac{7}{8}$	9	0·8750	0·8028	0·7307	22·225	0·11111	0·0722	$\frac{49}{64}$	0·7656
1	8	1·0000	0·9188	0·8376	25·400	0·12500	0·0812	$\frac{7}{8}$	0·8750
$1\frac{1}{8}$	7	1·1250	1·0322	0·9394	28·575	0·14285	0·0928	$\frac{63}{64}$	0·9844
$1\frac{1}{4}$	7	1·2500	1·1572	1·0644	31·750	0·14285	0·0928	$1\frac{7}{64}$	1·1093
$1\frac{1}{2}$	6	·15000	1·3917	1·2835	38·100	0·16666	0·1083	34·0 mm.	1·3386
$1\frac{3}{4}$	5	1·7500	1·6201	1·4902	44·450	0·20000	0·1299	39·5 mm.	1·5551
2	$4\frac{1}{2}$	2·0000	1·8557	1·7113	50·800	0·22222	0·1443	$1\frac{25}{32}$	1·7812
$2\frac{1}{4}$	$4\frac{1}{2}$	2·2500	2·1057	1·9613	57·150	0·22222	0·1443	$2\frac{1}{32}$	2·0312
$2\frac{1}{2}$	4	2·5000	2·3376	2·1752	63·500	0·25000	0·1624	$2\frac{1}{4}$	2·2500
$2\frac{3}{4}$	4	2·7500	2·5876	2·4252	69·850	0·25000	0·1624	$2\frac{1}{2}$	2·5000
3	4	3·0000	2·8376	2·6752	76·200	0·25000	0·1624	70·0 mm.	2·7559

* Approximately 83 % Full Thread.

AMERICAN 8-PITCH, 12-PITCH, AND 16-PITCH THREAD SERIES

Diameter inches	Threads per inch		
	8-Pitch Series	12-Pitch Series	16-Pitch Series
$\frac{1}{2}$	—	12	—
$\frac{9}{16}$	—	12	—
$\frac{5}{8}$	—	12	—
$\frac{11}{16}$	—	12	—
$\frac{3}{4}$	—	12	16
$\frac{13}{16}$	—	12	16
$\frac{7}{8}$	—	12	16
$\frac{15}{16}$	—	12	16
1	8	12	16
$1\frac{1}{16}$	—	12	16
$1\frac{1}{8}$	8	12	16
$1\frac{3}{16}$	—	12	16
$1\frac{1}{4}$	8	12	16
$1\frac{5}{16}$	—	12	16
$1\frac{3}{8}$	8	12	16
$1\frac{7}{16}$	—	12	16
$1\frac{1}{2}$	8	12	16
$1\frac{9}{16}$	—	—	16
$1\frac{5}{8}$	8	12	16
$1\frac{11}{16}$	—	—	16
$1\frac{3}{4}$	8	12	16
$1\frac{13}{16}$	—	—	16
$1\frac{7}{8}$	8	12	16
$1\frac{15}{16}$	—	—	16
2	8	12	16
$2\frac{1}{16}$	—	—	16
$2\frac{1}{8}$	8	12	16
$2\frac{3}{16}$	—	—	16
$2\frac{1}{4}$	8	12	16
$2\frac{5}{16}$	—	—	16
$2\frac{3}{8}$	—	12	16
$2\frac{7}{16}$	—	—	16
$2\frac{1}{2}$	8	12	16
$2\frac{5}{8}$	—	12	16
$2\frac{3}{4}$	8	12	16
$2\frac{7}{8}$	—	12	16
3	8	12	16
$3\frac{1}{8}$	—	12	16
$3\frac{1}{4}$	8	12	16
$3\frac{3}{8}$	—	12	16
$3\frac{1}{2}$	8	12	16
$3\frac{5}{8}$	—	12	16
$3\frac{3}{4}$	8	12	16
$3\frac{7}{8}$	—	12	16
4	8	12	16
$4\frac{1}{4}$	8	12	—
$4\frac{1}{2}$	8	12	—
$4\frac{3}{4}$	8	12	—
5	8	12	—
$5\frac{1}{4}$	8	12	—
$5\frac{1}{2}$	8	12	—
$5\frac{3}{4}$	8	12	—
6	8	12	—

29-DEGREE WORM THREAD

This is similar to the Acme thread, but the depth proportions differ.

p = pitch $= \dfrac{1}{\text{No. of threads per inch.}}$

d = depth of thread $= 0{\cdot}6866\ p = \dfrac{0{\cdot}6866}{\text{No. of threads per inch.}}$

t = width at top of thread $= 0{\cdot}335\ p$.

b = width at bottom of thread $= 0{\cdot}310\ p$.

Threads per inch	Depth of Thread	Double Depth of Thread	Width of Flat at Top of Thread	Width of Flat at Bottom of Thread
1	0·6866	1·3732	0·3350	0·3100
1¼	0·5492	1·0984	0·2680	0·2480
1½	0·4577	0·9144	0·2233	0·206
2	0·3433	0·6866	0·1675	0·1550
2½	0·2746	0·5492	0·1340	0·1240
3	0·2289	0·4577	0·1117	0·1033
3½	0·1962	0·3924	0·0957	0·0886
4	0·1716	0·3433	0·0838	0·0775
4½	0·1526	0·3052	0·0744	0·0689
5	0·1373	0·2746	0·0670	0·0620
6	0·1144	0·2289	0·0558	0·0517
7	0·0981	0·1962	0·0479	0·0443
8	0·0858	0·1716	0·0419	0·0388
9	0·0763	0·1526	0 0372	0·0344
10	0·0687	0·1373	0·0335	0·0310
12	0·0572	0·1144	0·0279	0·0258
16	0·0429	0·0858	0·0209	0·0194
20	0·0343	0·0687	0·0167	0·0155

Gas Fixture Threads.—Thin brass tubing is threaded with 27 threads per inch, irrespective of diameter. The so-called "ornament brass sizes" have 32 threads per inch. The standard sizes of the thread are 0·196 inch (large ornament brass size) and 0·148 inch (small ornament brass size).

GAS THREADS

(Brass Pipe Sizes)

Nominal Size	Actual Diam. of Thread	Threads per inch	Nominal Size	Actual Diam. of Thread	Threads per inch	Nominal Size	Actual Diam. of Thread	Threads per inch
0·148	0·148	32	⅜	0·390	27	¾	0·770	27
0·196	0·196	32	7/16	0·459	27	⅞	0·885	27
No. 4	0·246	27	½	0·515	27	1	1·006	27
¼	0·260	27	9/16	0·578	27	—	—	—
5/16	0·342	27	⅝	0·637	27	—	—	—

INTERNATIONAL METRIC FINE THREAD

(Dimensions in millimetres)

The form is similar to the International Screw-thread System but the pitch is smaller.

Pitch	Effective or Pitch Diam.	Major Diam.	Nut		Screw	
			Major Diam.	Minor Diam.	Minor or Core Diam.	Core Area Sq. mm.
0·2	0·870	1	1·02	0·74	0·72	0·41
0·2	1·070	1·2	1·22	0·94	0·92	0·66
0·2	1·270	1·4	1·42	1·14	1·12	0·98
0·2	1·570	1·7	1·72	1·44	1·42	1·58
0·25	1·838	2	2·03	1·68	1·65	2·13
0·25	2·138	2·3	2·33	1·98	1·95	2·98
0·35	2·373	2·6	2·64	2·15	2·11	3·49
0·35	2·773	3	3·04	2·55	2·51	4·94
0·35	3·273	3·5	3·54	3·05	3·01	7·10
0·5	3·675	4	4·05	3·35	3·30	8·53
0·5	4·175	4·5	4·55	3·85	3·80	11·32
0·5	4·675	5	5·05	4·35	4·30	14·50
0·75	5·513	6	6·08	5·03	4·94	19·20
0·75	6·513	7	7·08	6·03	5·94	27·75
1	7·350	8	8·11	6·70	6·59	34·14
1	8·350	9	9·11	7·70	7·59	45·28
1	9·350	10	10·11	8·70	8·59	57·99
1·5	11·026	12	12·16	10·05	9·89	76·81
1·5	13·026	14	14·16	12·05	11·89	111
1·5	15·026	16	16·16	14·05	13·89	152
1·5	17·026	18	18·16	16·05	15·89	198
1·5	19·026	20	20·16	18·05	17·89	251
1·5	21·026	22	22·16	20·05	19·89	311
2	22·701	24	24·22	21·40	21·19	353
2	25·701	27	27·22	24·40	24·19	459
2	28·701	30	30·22	27·40	27·19	580
2	31·701	33	33·22	30·40	30·19	716
3	34·051	36	36·32	32·10	31·78	793
3	37·051	39	39·32	35·10	34·78	950
3	40·051	42	42·32	38·10	37·78	1121
3	43·051	45	45·32	41·10	40·78	1306
3	46·051	48	48·32	44·10	43·78	1505
3	50·051	52	52·32	48·10	47·78	1793
4	53·402	56	56·43	50·80	50·37	1993
4	57·402	60	60·43	54·80	54·37	2322
4	61·402	64	64·43	58·80	58·37	2676
4	69·402	72	72·43	66·80	66·37	3460
4	77·402	80	80·43	74·80	74·37	4344

METRIC THREAD (TRAPEZOIDAL)

Pitch mm. P	Depth of Thread, mm. d	Depth of Nut Thread e	Contact Depth, mm. h	Rounding mm. (Optional)	Clearance, mm.	
					a	b
3	1·75	1·50	1·25	0·25	0·25	0·25
4	2·25	2·00	1·75	0·25	0·25	0·5
5	2·75	2·25	2	0·25	0·25	0·75
6	3·25	2·75	2·5	0·25	0·25	0·75
7	3·75	3·25	3	0·25	0·25	0·75
8	4·25	3·75	3·5	0·25	0·25	0·75
9	4·75	4·25	4	0·25	0·25	0·75
10	5·25	4·75	4·5	0·25	0·25	0·75
12	6·25	5·75	5·5	0·25	0·25	0·75
14	7·5	6·5	6	0·5	0·5	1·5
16	8·5	7·5	7	0·5	0·5	1·5
18	9·5	8·5	8	0·5	0·5	1·5
20	10·5	9·5	9	0·5	0·5	1·5
22	11·5	10·5	10	0·5	0·5	1·5
24	12·5	11·5	11	0·5	0·5	1·5
26	13·5	12·5	12	0·5	0·5	1·5

PROGRESS THREADS

(Used for watch screws. Included thread angle, 50 degrees. Depth of thread = 0·8 pitch. Depth of rounding = 0·093 × pitch. Radius = 0·0732 × pitch.)

Size Number	Pitch mm.	Diameter mm.	Size Number	Pitch mm. Two sizes from 16 to 20		Diameter mm.
4	0·100	0·40	9½	0·225	—	0·95
4½	0·100	0·45	10	0·250	—	1·0
5	0·125	0·50	11	0·275	—	1·1
5½	0·125	0·55	12	0·300	—	1·2
6	0·150	0·60	13	0·325	—	1·3
6½	0·150	0·65	14	0·350	—	1·4
7	0·175	0·70	15	0·375	—	1·5
7½	0·175	0·75	16	0·32	0·457	1·6
8	0·200	0·80	17	0·34	0·486	1·7
8½	0·200	0·85	18	0·36	0·514	1·8
9	0·225	0·90	19	0·38	0·543	1·9
			20	0·40	0·571	2

S. F. FRENCH THREAD

This thread has the same form and proportions as the American (formerly U.S.) standard and is gradually being superseded by the International Metric Thread.

FRENCH STANDARD THREAD

Pitch mm.	Diameter		Root Diameter		Pitch mm.	Diameter		Root Diameter	
	mm.	inches	mm.	inches		mm.	inches	mm.	inches
0·5	3	0·1181	2·35	0·0925	3·0	24	0·9449	20·10	0·7915
0·75	4	0·1575	3·03	0·1191	3·0	26	1·0236	22·10	0·8702
0·75	5	0·1969	4·03	0·1585	3·0	28	1·1024	24·10	0·9490
1·0	6	0·2362	4·70	0·1851	3·5	30	1·1811	25·45	1·0020
1·0	7	0·2756	5·70	0·2245	3·5	32	1·2598	27·45	1·0807
1·0	8	0·3150	6·70	0·2639	3·5	34	1 3386	29·45	1·1595
1·0	9	0·3543	7·70	0·3032	4·0	36	1·4173	30·80	1·2126
1·5	10	0·3937	8·05	0·3170	4·0	38	1·4961	32·80	1·2914
1·5	12	0·4724	10·05	0·3957	4·0	40	1·5748	34·80	1·3701
2·0	14	0·5512	11·40	0·4489	4·5	42	1·6535	36·15	1·4232
2·0	16	0·6299	13·40	0·5276	4·5	44	1·7523	38·15	1·5020
2·5	18	0·7087	14·75	0·5808	4·5	46	1·8110	40·15	1·5807
2·5	20	0·7874	16·75	0·6595	5·0	48	1·8898	41·51	1·6343
2·5	22	0·8661	18·75	0·7382	5·0	50	1·9685	43·51	1·7130

FRENCH METRIC THREADS

The French metric thread form is similar to the International system. Sizes between 6 and 90 mm. are the same as the International system. Sizes above 100 mm. increase by 5 mm. Under 3 mm. the angle may be either 50 or 60 degrees. Thread depth=0·704×pitch and clearance between the root of the thread and the crest=0·054×pitch.

Pitch mm.	Effective or Pitch Diam.	Major Diam., mm.	Minor or Core Diam.	Pitch mm.	Effective or Pitch Diam.	Major Diam., mm.	Minor or Core Diam.
0·075	0·251	0·3	0·194	0·300	1·405	1·6	1·180
0·075	0·301	0·35	0·244	0·400	1·540	1·8	1·240
0·100	0·335	0·4	0·259	0·400	1·740	2	1·440
0·100	0·385	0·45	0·309	0·450	1·907	2·2	1·570
0·125	0·419	0·5	0·324	0·450	2·207	2·5	1·870
0·125	0·469	0·55	0·374	0·6	2·610	3	2·16
0·150	0·502	0·6	0·389	0·75	3·513	4	2·94
0·150	0·602	0·7	0·489	0·9	4·415	5	3·73
0·200	0·670	0·8	0·518	1	5·350	6	4·59
0·200	0·770	0·9	0·618	6	86·103	90	81·56
0·250	0·837	1	0·650	6	91·103	95	86·56
0·250	1·037	1·2	0·850	6	96·103	100	91·56
0·300	1·205	1·4	0·980				

GERMAN METRIC THREAD

(All dimensions in millimetres)

Similar to International Standard, but depth is 0·6945 pitch; clearance between root and crest is 0·045 pitch, radius at root is 0·0633 pitch. From 6 mm. to 12 mm. sizes and proportions follow International Metric Thread.

Pitch	Effective or Pitch Diam.	Nut		Screw		
		Major Diam.	Minor or Core Diam.	Major Diam.	Minor or Core Diam.	Core Area, Sq. Cm.
1·75	10·863	12·16	9·726	12	9·570	0·718
2	12·701	14·180	11·402	14	11·222	0·989
2	14·701	16·180	13·402	16	13·222	1·373
2·5	16·376	18·224	14·752	18	14·528	1·657
2·5	18·376	20·224	16·752	20	16·528	2·145
2·5	20·376	22·224	18·752	22	18·528	2·696
3	22·051	24·270	20·102	24	19·832	3·080
3	25·051	27·270	23·102	27	22·832	4·094
3·5	27·727	30·316	25·454	30	25·138	4·963
3·5	30·727	33·316	28·454	33	28·138	6·218
4	33·402	36·360	30·804	36	30·444	7·279
4	36·402	39·360	33·804	39	33·444	8·785
4·5	39·077	42·404	36·154	42	35·750	10·04
4·5	42·077	45·404	39·154	45	38·750	11·79
5	44·752	48·450	41·504	48	41·054	13·23
5	48·752	52·450	45·505	52	45·054	15·94
5·5	52·428	56·496	48·856	56	48·360	18·37
5·5	56·428	60·496	52·856	60	52·360	21·53
6	60·103	64·54	56·206	64	55·666	24·34
6	64·103	68·54	60·206	68	59·666	27·96
6	68·103	72·54	64·206	72	63·666	31·83
6	72·103	76·54	68·206	76	67·666	35·96
6	76·103	80·54	72·206	80	71·666	40·34
6	80·103	84·54	76·206	84	75·666	44·96
6	85·103	89·54	81·206	89	80·666	51·10
6	90·103	94·54	86·206	94	85·666	57·64
6	95·103	99·54	91·206	99	90·666	64·56
6	100·103	104·54	96·206	104	95·666	71·88
6	105·103	109·54	101·206	109	100·666	79·59
6	110·103	114·54	106·206	114	105·666	87·69
6	115·103	119·54	111·206	119	110·666	96·18
6	120·103	124·54	116·206	124	115·666	105·07
6	125·103	129·54	121·206	129	120·666	114·35
6	130·103	134·54	126·206	134	125·666	124·04
6	135·103	139·54	131·206	139	130·666	134·09
6	140·103	144·54	136·206	144	135·666	144·10
6	145·103	149·54	141·206	149	140·666	155·40

GERMAN METRIC FINE THREAD

Similar to the German metric thread, but pitch is finer. Sizes continue from 102 mm. up to 190 mm. with pitch of 3 mm.; up to 300 mm. pitch of 4 mm.

Pitch	Effective or Pitch Diam.	Nut		Screw		
		Major Diam.	Minor or Core Diam.	Major Diam.	Minor or Core Diam.	Core Area, Sq. Cm.
0·20	0·870	1·018	0·740	1	0·722	0·00409
0·20	1·070	1·218	0·940	1·2	0·922	0·00668
0·20	1·270	1·418	1·140	1·4	1·122	0·00989
0·20	1·570	1·718	1·440	1·7	1·422	0·0159
0·20	1·870	2·018	1·740	2	1·722	0·0233
0·25	2·138	2·324	1·976	2·3	1·952	0·0299
0·25	2·438	2·624	2·276	2·6	2·252	0·0398
0·35	2·773	3·032	2·546	3	2·514	0·0496
0·35	3·273	3·532	3·046	3·5	3·014	0·0713
0·35	3·773	4·032	3·546	4	3·514	0·0970
0·5	4·175	4·544	3·850	4·5	3·806	0·114
0·5	4·675	5·044	4·350	5	4·306	0·146
0·75	5·513	6·068	5·026	6	4·958	0·193
0·75	6·513	7·068	6·026	7	5·958	0·279
0·75	7·513	8·068	7·026	8	6·958	0·380
1	8·350	9·090	7·700	9	7·610	0·455
1	9·350	10·090	8·700	10	8·610	0·582
1·5	11·026	12·136	10·052	12	9·916	0·772
1·5	13·026	14·136	12·052	14	11·916	1·115
1·5	15·026	16·136	14·052	16	13·916	1·521
1·5	17·026	18·136	16·052	18	15·916	1·990
1·5	19·026	20·136	18·052	20	17·916	2·521
1·5	21·026	22·136	20·052	22	19·916	3·115
1·5	23·026	24·136	22·052	24	21·916	3·772
1·5	26·026	27·136	25·052	27	24·916	4·876
1·5	29·026	30·136	28·052	30	27·916	6·121
1·5	32·026	33·136	31·052	33	30·916	7·507
1·5	35·026	36·136	34·052	36	33·916	9·034
1·5	39·026	40·136	38·052	40	37·916	11·29
1·5	41·026	42·136	40·052	42	39·916	12·51
1·5	44·026	45·136	43·052	45	42·916	14·47
1·5	47·026	48·136	46·052	48	45·916	16·56
1·5	49·026	50·136	48·052	50	47·916	18·03
1·5	51·026	52·136	50·052	52	49·916	19·57
2	54·701	56·180	53·402	56	53·222	22·25
2	58·701	60·180	57·402	60	57·222	25·72
2	62·701	64·180	61·402	64	61·222	29·44
2	66·701	68·180	65·402	68	65·222	33·41
2	70·701	72·180	69·402	72	69·222	37·63
2	74·701	76·180	73·402	76	73·222	42·11
2	78·701	80·180	77·402	80	77·222	46·84
2	83·701	85·180	82·402	85	82·222	53·10
2	88·701	90·180	87·402	90	87·222	59·75
2	93·701	95·180	92·402	95	92·222	66·80
2	98·701	100·180	97·402	100	97·222	74·24

SCREW THREAD GAUGE TOLERANCES

"GO" PLUG SCREW GAUGES

B.S. No. 919-1940

Limits of Tolerance, Unit=0·0001 in.

Size of Gauge	Up to and including 1·5 in.	Above 1·5 in. up to and including 3 in.	Above 3 in. up to and including 6 in.
INSPECTION GAUGES			
Major Diameter	+0 −6	+0 −9	+0 −14
Simple Effective Diameter	+0 −4	+0 −6	+0 −8
Effective Diameter Equivalent of Pitch and Angle Errors not to exceed	5	6	8
Minor Diameter	+0 −10	+0 −15	+0 −21
WORKSHOP GAUGES			
Major Diameter	+6 −0	+9 −0	+14 −0
Simple Effective Diameter	+6 +2	+9 +3	+14 +6
Effective Diameter Equivalent of Pitch and Angle Errors not to exceed	5	6	8
Minor Diameter	+6 −4	+9 −6	+14 −7

"NOT GO" EFFECTIVE DIAMETER PLUG GAUGES

B.S. No. 919-1940

Threads cleared at Crests and Roots.
Length not to exceed 3 threads.
Limits of Tolerance, Unit=0·0001 in.

INSPECTION GAUGES
(Also recommended temporarily for Workshop Gauges)

Simple Effective Diameter	+4 −0	+6 −0	+8 −0
Effective Diameter Equivalent of Angle Error not to exceed	3	3	4

"NOT GO" PLAIN PLUG GAUGES

B.S. No. 919-1940

Limits of Tolerance, Unit=0·0001 in.

INSPECTION GAUGES
(Also recommended temporarily for Workshop Gauges)

Limits of Tolerance on Plain Diameter	+3 −0	+4 −0	+5 −0

Note.—Cylindrical-ended bar gauges are preferable to plug gauges over 3 in.

"GO" RING SCREW AND "GO" THREAD CALIPER GAUGES
B.S. No. 919-1940

Limits of Tolerance, Unit=0·0001 in.

Size of Gauge	Up to and including 1·5 in.	Above 1·5 in. up to and including 3 in.	Above 3 in. up to and including 6 in.
INSPECTION GAUGES			
Major Diameter	+9 −0	+14 − 0	+21 − 0
Effective Diameter	+6 −0	+ 9 − 0	+14 − 0
Minor Diameter	+6 −0	+ 0 − 0	+14 − 0
WORKSHOP GAUGES			
Major Diameter	+3 −6	+ 5 − 9	+ 7 −14
Effective Diameter	+0 −6	+ 0 − 9	+ 0 −14
Minor Diameter	+0 −6	+ 0 − 9	+ 0 −14

"NOT GO" EFFECTIVE DIAMETER RING SCREW GAUGES AND THREAD CALIPER GAUGES
B.S. No. 919-1940

Threads cleared at Crests and Roots.
Length not to exceed 3 threads.
Limits of Tolerance, Unit=0·0001 in.

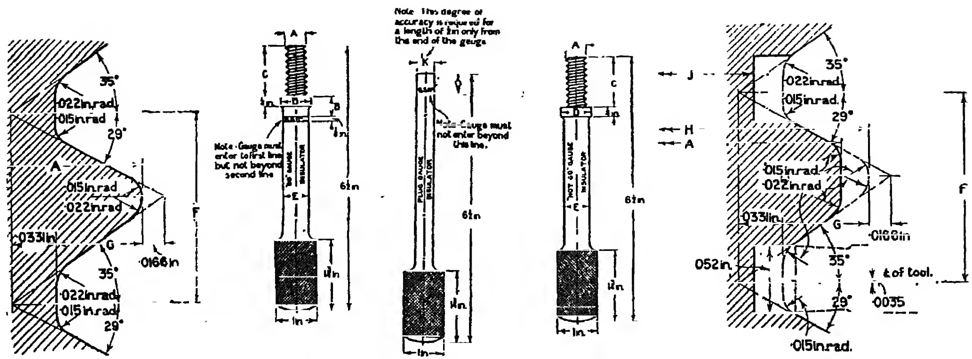
INSPECTION GAUGES (Also recommended temporarily for Workshop Gauges)			
Effective Diameter	+0 −3	+0 −5	+0 −7

Note.—"Not go" effective diameter ring screw gauges should be used only in exceptional circumstances.

"NOT GO" PLAIN GAP GAUGES
B.S. No. 919-1940

Limits of Tolerance, Unit=0·0001 in.

INSPECTION GAUGES (Also recommended temporarily for Workshop Gauges)			
Limits of Tolerance on Plain Gap .	+0 −3	+0 −4	+0 −5



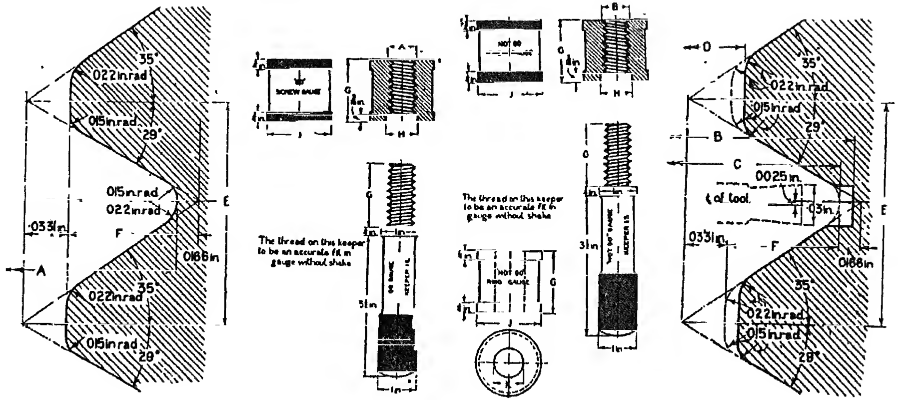
THE CORDEAUX SCREW THREAD

(Used by G.P.O. for Telephone Wire Cup Fittings)

TABLE OF DIMENSIONS FOR INSULATOR GAUGES

Insulator		Gauge					Gauge Thread				Plug		Tell-Tale Gauge								
Size	B.S. No.	A	B*	C	D	E	F	G	H	J	U	K	B*	L	M	N	P	Q	R	S	T
in. $\frac{1}{2}$	3	in. ·5025	in. $\frac{7}{16}$	in. $1\frac{1}{4}$	in. $\frac{11}{16}$	in. $\frac{9}{16}$	in. ·1429	in. ·0625	in. ·5445	in. ·3764	in. $\frac{5}{8}$	in. ·4345	in. $\frac{7}{16}$	in. $\frac{1}{4}$	in. $\frac{3}{16}$	in. $1\frac{3}{8}$	in. $\frac{11}{16}$	in. $\frac{7}{32}$	in. $\frac{3}{8}$	in. $\frac{13}{32}$	in. $7\frac{7}{16}$
$\frac{5}{8}$	1 & 7 2, 8 & 10 16 & 21	·6275	$2\frac{11}{16}$ $2\frac{1}{16}$ $1\frac{13}{16}$	$1\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	·1667	·0832	·6695	·4600	$2\frac{7}{8}$ $2\frac{1}{4}$ 2	·5181	$2\frac{11}{16}$ $2\frac{1}{16}$ $1\frac{13}{16}$	$\frac{3}{8}$	$\frac{9}{32}$	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{13}{32}$	$7\frac{7}{16}$

* Dimension B is equal to the distance from the bottom of the insulator thread to the bottom of the shed, less $\frac{1}{16}$ in.



THE CORDEAUX SCREW THREAD *(continued)*

TABLE OF DIMENSIONS FOR INSULATOR SPINDLE GAUGES

Spindle Thread Diameter	Thread						Gauge			
	A	B	C	D	E	F	G	H	J	K
in. $\frac{1}{2}$	in. ·5025	in. ·5050	in. ·4850	in. ·3775	in. ·1429	in. ·0625	in. $1\frac{3}{16}$	in. $\frac{9}{16}$	in. $1\frac{1}{4}$	in. ·4850
$\frac{5}{8}$	·6275	·6300	·6100	·4611	·1667	·0832	$1\frac{3}{16}$	$\frac{11}{16}$	$1\frac{1}{4}$	·6100
Tolerances for all sizes	+ ·001 − 0	min.	+ 0 − ·0015	+ ·001 − 0	—	—	—	—	—	+ 0 − ·0005

BRITISH STANDARD HEADS FOR BRITISH ASSOCIATION

All dimensions are given in mils. except where

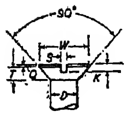


Fig. 1.—Countersunk.

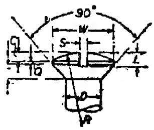


Fig. 2.—Instrument.

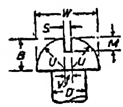


Fig. 3.—Round.

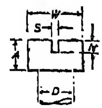


Fig. 4.—Cheese.

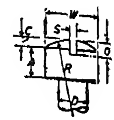


Fig. 5.—Filister.

Col. 1	2	3	4	5	6	7	8	9	10
B.A. Designating Number	Diameter of Shank and Full Diameter of Thread		Diameter of Head	Tolerances on Dimensions marked W	Diameter of Head of Connection Screw	Tolerance on Dia. of Head of Connection Screw. Col. 6	Depth of Coned Portion Head	Part Depth of Head (see Figs. 1 & 2)	Part Depth of Head (see Figs. 2 & 5)
	D		W 1·75 D		X		T ·375 D	·05 D+0·1 mm. Q Maximum	C 0 2 D
	mm.	mils.	mils.	mils.	mils.	mils.	mils.	mils.	mils.
0	6·0	236	413	–8	472	–8	89	16	47
1	5·3	209	365	–8	413	–8	78	14	42
2	4·7	185	324	–8	365	–8	69	13	37
3	4·1	161	282	–6	324	–8	61	12	32
4	3·6	142	248	–6	282	–6	53	11	28
5	3·2	126	220	–6	248	–6	47	10	25
6	2·8	110	193	–5	220	–6	41	9	22
7	2·5	98	172	–5	193	–5	37	9	20
8	2·2	87	152	–5	172	–5	32	8	17
9	1·9	75	131	–4	152	–5	28	8	15
10	1·7	67	117	–4	131	–4	25	7	13
11	1·5	59	103	–4	117	–4	22	7	12
12	1·3	51	90	–4	103	–4	19	6	10

SCREWS. Schedule of Dimensions (B.S. 57–1920).

otherwise stated. One mil. = ·001 of an inch.

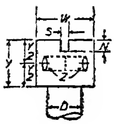


Fig. 6.—Capstan.

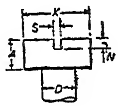


Fig. 7.—Connection.

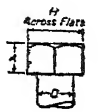


Fig. 8.—Hexagon.

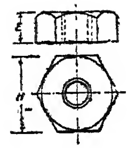


Fig. 9.—Hexagon nut.

11	12	13	14	15	16	17	18
Total Depth of Head							
Countersunk	Instrument	Tolerance on Cols. 11 12	Round	Hexagon, Cheese, Connection	Filister	Capstan	Tolerance on Cols. 14, 15, 16, 17
T+Q ·425 D+0·1 mm.	T+Q+C 0·625 D+0·1 mm.		B 0·8 D	A 0·75 D	A+C 0·95 D	Y 1·4 D	
mils.	mils.	mils.	mils.	mils.	mils.	mils.	mils.
105	152	–4	189	177	224	330	–8
92	134	–4	167	156	198	293	–7
82	119	–4	148	139	176	259	–7
73	105	–3	129	121	153	225	–6
64	92	–3	113	106	134	199	–6
57	82	–3	101	94	119	176	–5
50	72	–3	88	83	105	154	–5
46	66	–3	79	74	94	137	–4
40	57	–3	69	65	82	122	–4
36	51	–2	60	56	71	105	–4
32	45	–2	54	50	63	94	–4
29	41	–2	47	44	56	83	–3
25	35	–2	41	38	48	71	–3

[*This Table is continued overleaf*

BRITISH STANDARD HEADS FOR BRITISH ASSOCIATION

All dimensions are given in mils. except where

Col. 19	20	21	22	23	24	25	26
B.A. Designating Number	Width of Saw Cut		Depth of Saw Cut				
	See Notes for Tolerances		See Notes for Tolerances				
			Countersunk	Instrument	Round	Connection, Cheese, Capstan	Filister
	S 0·2 D+0·1 mm.		K 0 22 D (App.)	L 0 31 D (App.)	M 0·4 D	N 0·375 D	O 0·475 D
	S.W.G. No.	mils.	mils.	mils.	mils.	mils.	mils.
0	18	48	52	76	94	89	112
1	18	48	47	68	83	78	99
2	19	40	43	61	74	69	88
3	19	40	36	52	65	61	77
4	21	32	32	47	57	53	67
5	21	32	30	42	50	47	60
6	23	24	25	36	44	41	52
7	23	24	22	32	39	37	47
8	23	24	20	29	35	32	41
9	26	18	18	25	30	28	36
10	26	18	16	23	27	25	32
11	26	18	15	21	24	22	28
12	30	12·4	14	19	20	19	28

Notes on Table.—The Tolerances on Diameter and Depths of Heads are in the Table. The Association recommends that the be from −7% to +8% of the dimensions given in the calculated figure.

SPARKING-PLUG THREADS

Diameter	Pitch	Thread Standard
18 mm.	1·5 mm.	Metric
14 mm.	1·25 mm.	,,
12 mm.	1·25 mm.	,,
10 mm.	1·0 mm.	,,
$\frac{7}{8}$ in.	18 t.p.i.	S.A.E.
$\frac{5}{8}$ in.	24 t.p.i.	,,
$\frac{1}{4}$ in.	24 t.p.i.	,,

SCREWS. Schedule of Dimensions (B.S. 57–1920)—*continued*
otherwise stated. One mil.=0·001 of an inch.

27	28	29	30	31	32	33
Radii			Diameter of Spike Holes in Capstan Head	Hexagon Heads and Nuts		Tolerance on Width across Flats of Hexagon Heads and Nuts
Round Head	Round Head. Distance between Centres	Instrument and Filister		Width across Flats	Thickness of Nuts — Ordinary	
U 0·8 D	V	R 2·0 D	Z	H 1·75 D	E 1·0 D	
mils.	mils.	mils.	mils.	mils.	mils.	mils.
189	35	472	120	413	236	−3
167	31	417	113	365	209	−3
148	28	370	107	324	185	−3
129	24	323	98	282	161	−3
113	21	283	89	248	142	−3
101	19	252	82	220	126	−3
88	17	220	76	193	110	−3
79	15	197	67	172	98	−2
69	13	173	59	152	87	−2
60	11	150	52	131	75	−2
54	10	134	43	117	67	−2
47	9	118	—	103	59	−2
41	8	102	—	90	51	−2

minus, i.e., the dimensions to which they refer should not exceed the values given
tolerances on the Widths and Depths of the Saw Cuts (columns 20 to 26 inclusive)
Table, such standard tolerances being determined by the nearest unit above the

Tolerances on Screw Threads Protected by Plating, etc.—The British Standards Institution recommend that the finished sizes of all external and internal screw threads after being coated shall not exceed the upper limits specified for them.

In order to avoid any undue restrictions of the tolerance allowed for screwing, the sizes of external screw threads before coating shall be not more than 0·001 in. smaller than their specified lower limits.

For the same reason, the sizes of internal screw threads before coating shall be allowed to be not more than 0·001 in. larger than their specified upper limits.

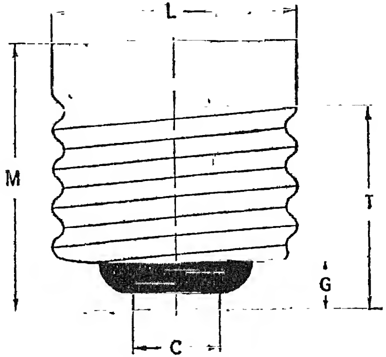


Fig. 1.—E.40/45 cap.

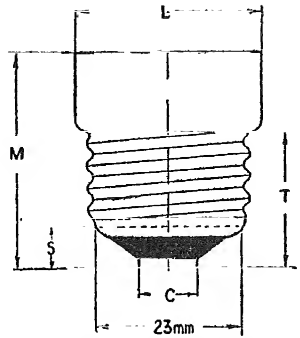


Fig. 2a.—E. 27/35 × 30 cap.

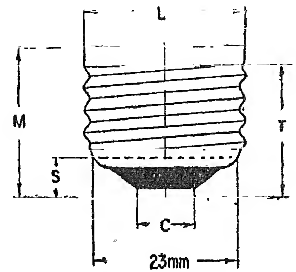


Fig. 2b.—E. 27/25 cap.

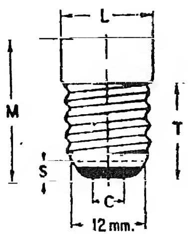


Fig. 3.—E. 14/23 × 15 cap.

EDISON TYPE ELECTRIC-
LAMP CAPS.

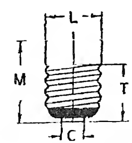


Fig. 4.—E. 10/13 cap.

TABLE 1.—DIMENSIONS OF LAMP CAPS
(See Figs. 1–4, page 618)

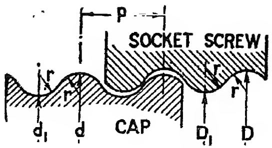
Cap Designation	L		M		C		G*		S		T	Min. Creeping Distance Over Surface of Insulation	Min. Thickness of Metal Shell
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
E. 40 . .	1·528	1·543	1·732	1·811	0·551	0·709	0·315	0·354	—	—	1·339	0·197	0·010
E. 27/35 × 30	1·177	1·185	1·358	1·398	0·374	0·453	—	—	0·276	0·315	0·866	0·118	0·007
E. 27/25 .	1·020	1·028	0·984	1·024	0·374	0·453	—	—	0·276	0·315	0·866	0·118	0·007
E. 14 . .	0·587	0·594	0·913	0·937	0·228	0·244	—	—	0·138	0·177	0·630	0·138	0·007
E. 10 . .	0·358	0·374	0·520	0·543	0·138	0·157	—	—	—	—	0·374	0·079	0·007

* This dimension is not agreed internationally. All other dimensions agree to the nearest 0·001 inch with those adopted by the International Electrotechnical Commission

TABLE 1 (a).—METRIC EQUIVALENTS OF DIMENSIONS IN TABLE 1

Cap Designation	L		M		C		G*		S		T	Min. Creeping Distance Over Surface of Insulation	Min. Thickness of Metal Shell
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.		
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
E. 40 . .	38·8	39·2	44·0	46·0	14·0	18·0	8·0	9·0	—	—	34·0	5	0·25
E. 27/35 × 30	29·9	30·1	34·5	35·5	9·5	11·5	—	—	7	8	22·0	3	0·18
E. 27/25 .	25·9	26·1	25·0	26·0	9·5	11·5	—	—	7	8	22·0	3	0·18
E. 14 . .	14·9	15·1	23·2	23·8	5·8	6·2	—	—	3·5	4·5	16·0	3·5	0·18
E. 10 . .	9·1	9·5	13·2	13·8	3·5	4·0	—	—	—	—	9·5	2	0·18

* This dimension is not agreed internationally. All other dimensions are in agreement with those adopted by the International Electrotechnical Commission.



Profile of screw thread.

TABLE 2.—DIMENSIONS OF PROFILE OF SCREW THREADS FOR LAMP CAPS AND SOCKET SCREWS

Cap Designation	r	p	Cap				Socket Screw			
			Major diameter d		Minor diameter d_1		Major diameter D		Minor diameter D_1	
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
	in.	in.	in.	in.	in.	in.	in.	in.	in	in.
E. 40 .	0·0728	0·2500	1·5374	1·5551	1·3957	1·4134	1·5591	1 5768	1·4173	1·4350
E. 27 .	0·0404	0·1429	1·0295	1·0413	0·9433	0·9551	1·0453	1·0571	0·9591	0·9709
E. 14 .	0·0324	0·1111	0·5394	0·5472	0·4764	0·4843	0·5496	0·5575	0·4866	0·4945
E. 10 .	0·0209	0·0714	0·3685	0·3752	0·3283	0·3350	0·3783	0·3850	0·3382	0·3449

NOTE.—The above dimensions agree to the nearest 0·0001 inch with those adopted by the International Electrotechnical Commission.

TABLE 2 (a).—METRIC EQUIVALENTS OF DIMENSIONS IN TABLE 2

Cap Designation	r	p	Cap				Socket Screw			
			Major diameter d		Minor diameter d_1		Major diameter D		Minor diameter D_1	
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
	mm.	mm.	mm.	mm.	mm	mm.	mm.	mm.	mm.	mm.
E. 40 .	1·85	6·350	39·05	39·50	35·45	35·90	39·60	40·05	36·00	36·45
E. 27 .	1·025	3·629	26·15	26·45	23·96	24·26	26·55	26·85	24·36	24·66
E. 14 .	0·822	2·822	13·70	13·90	12·10	12·30	13·96	14·16	12 36	12·56
E. 10 .	0·531	1·814	9·36	9·53	8·34	8·51	9·61	9·78	8·59	8·76

WHITWORTH AND B.S.F. SCREW HEADS (B.S. 450-1932)

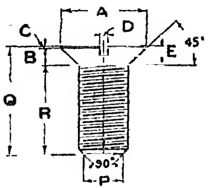


Fig. 1.—Countersunk-head screw.

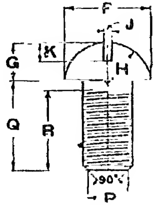


Fig. 2.—Round-head screw.

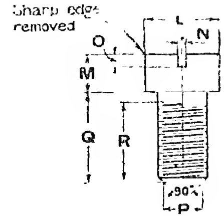


Fig. 3.—Cheese-head screw.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
			Countersunk-head screw					Round-head screw					Cheese-head screw				
Nominal size and maximum diameter of screw	Number of threads per inch		Diameter of head	Depth of countersunk portion of head	Depth of parallel portion of head	Width of slot	Depth of slot	Diameter of head	Depth of head	Radius of head	Width of slot	Depth of slot	Diameter of head	Depth of head	Width of slot	Depth of slot	Nominal size and maximum diameter of screw
	B.S.W.	B.S.F.	A	B	C	D	E	F	G	H	J	K	L	M	N	O	
in.			in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
$\frac{1}{8}$	40	—	0·219	0·047	0·010	0·032	0·033	0·219	0·100	0·110	0·032	0·050	0·187	0·100	0·032	0·040	$\frac{1}{8}$
$\frac{5}{32}$	32	—	0·273	0·058	0·010	0·040	0·039	0·273	0·125	0·137	0·040	0·062	0·234	0·125	0·040	0·050	$\frac{5}{32}$
$\frac{3}{16}$	24	32	0·328	0·070	0·010	0·040	0·045	0·328	0·150	0·165	0·040	0·075	0·281	0·150	0·040	0·060	$\frac{3}{16}$
$\frac{1}{4}$	20	26	0·437	0·094	0·010	0·062	0·057	0·437	0·200	0·220	0·062	0·100	0·375	0·200	0·062	0·080	$\frac{1}{4}$
$\frac{5}{16}$	18	22	0·547	0·117	0·015	0·062	0·073	0·547	0·250	0·274	0·062	0·125	0·469	0·250	0·062	0·100	$\frac{5}{16}$
$\frac{3}{8}$	16	20	0·656	0·141	0·015	0·084	0·085	0·656	0·300	0·329	0·084	0·150	0·562	0·300	0·084	0·120	$\frac{3}{8}$
$\frac{7}{16}$	14	18	0·766	0·164	0·015	0·084	0·097	0·766	0·350	0·384	0·084	0·175	0·656	0·350	0·084	0·123	$\frac{7}{16}$
$\frac{1}{2}$	12	16	0·875	0·187	0·015	0·093	0·108	0·875	0·400	0·439	0·093	0·200	0·750	0·400	0·093	0·140	$\frac{1}{2}$
$\frac{9}{16}$	11	14	1·094	0·234	0·020	0·093	0·137	1·094	0·500	0·549	0·093	0·250	0·937	0·500	0·093	0·175	$\frac{9}{16}$
$\frac{5}{8}$	10	12	1·312	0·281	0·020	0·144	0·160	1·312	0·600	0·659	0·144	0·300	1·125	0·600	0·144	0·210	$\frac{5}{8}$
$\frac{3}{4}$	9	11	1·531	0·328	0·020	0·160	0·184	1·531	0·700	0·769	0·160	0·350	1·312	0·700	0·160	0·245	$\frac{3}{4}$
$\frac{7}{8}$	8	10	1·750	0·375	0·020	0·176	0·207	1·750	0·800	0·878	0·176	0·400	1·500	0·800	0·176	0·280	$\frac{7}{8}$
1																	1

SCREWS. Schedule of Dimensions (B.S. 57–1920).

otherwise stated. One mil.=·001 of an inch.

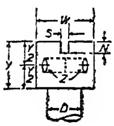


Fig. 6.—Capstan.

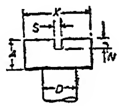


Fig. 7.—Connection.

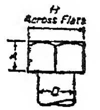


Fig. 8.—Hexagon.

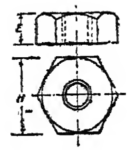


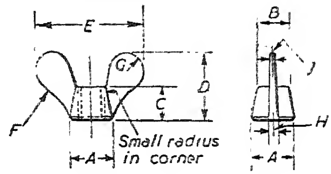
Fig. 9.—Hexagon nut.

11	12	13	14	15	16	17	18
Total Depth of Head							
Countersunk	Instrument	Tolerance on Cols. 11 12	Round	Hexagon, Cheese, Connection	Filister	Capstan	Tolerance on Cols. 14, 15, 16, 17
T+Q ·425 D+0·1 mm.	T+Q+C 0·625 D+0·1 mm.		B 0·8 D	A 0·75 D	A+C 0·95 D	Y 1·4 D	
mils.	mils.	mils.	mils.	mils.	mils.	mils.	mils.
105	152	−4	189	177	224	330	−8
92	134	−4	167	156	198	293	−7
82	119	−4	148	139	176	259	−7
73	105	−3	129	121	153	225	−6
64	92	−3	113	106	134	199	−6
57	82	−3	101	94	119	176	−5
50	72	−3	88	83	105	154	−5
46	66	−3	79	74	94	137	−4
40	57	−3	69	65	82	122	−4
36	51	−2	60	56	71	105	−4
32	45	−2	54	50	63	94	−4
29	41	−2	47	44	56	83	−3
25	35	−2	41	38	48	71	−3

[*This Table is continued overleaf*

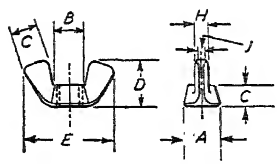
DIMENSIONS OF WING NUTS

Hot Brass or other Non-Ferrous Stampings; Malleable Iron Castings; Hot Steel Stampings.



1	2	3	4	5	6	7	8	9	10	11	12
No.*	Nominal Size of Screw Thread: B.S.W. and B.S.F.	Nominal Size of Screw Thread: B.A.	A	B	C	D	E	F	G	H	J
	in.		in.	in.	in.	in.	in.	in.	in.	in.	in.
1	$\frac{1}{8}$	4 and 5	$\frac{11}{32}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{17}{32}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{9}{64}$	$\frac{3}{32}$	$\frac{1}{16}$
2	$\frac{3}{16}$	2 and 3	$\frac{13}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{19}{32}$	1	$\frac{3}{4}$	$\frac{5}{32}$	$\frac{3}{32}$	$\frac{1}{16}$
3	$\frac{1}{4}$	o and 1	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{25}{32}$	$1\frac{3}{16}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{1}{16}$
4	$\frac{5}{16}$	—	$\frac{5}{8}$	$\frac{15}{32}$	$\frac{1}{2}$	$\frac{29}{32}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{32}$
5	$\frac{3}{8}$	—	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	1	$1\frac{3}{4}$	$\frac{3}{4}$	$\frac{9}{32}$	$\frac{3}{16}$	$\frac{1}{8}$
6	$\frac{7}{16}$	—	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{19}{32}$	$1\frac{1}{8}$	2	1	$\frac{5}{16}$	$\frac{3}{16}$	$\frac{1}{8}$
7	$\frac{1}{2}$	—	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{21}{32}$	$1\frac{1}{4}$	$2\frac{3}{16}$	1	$\frac{3}{8}$	$\frac{7}{32}$	$\frac{5}{32}$
8	$\frac{5}{8}$	—	1	$\frac{13}{16}$	$\frac{3}{4}$	$1\frac{7}{16}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$\frac{13}{32}$	$\frac{1}{4}$	$\frac{3}{16}$
9	$\frac{3}{4}$	—	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{7}{8}$	$1\frac{5}{8}$	$3\frac{1}{16}$	$1\frac{1}{2}$	$\frac{15}{32}$	$\frac{9}{32}$	$\frac{7}{32}$

Mild Steel, Cold Forged; Brass, Cold Forged.



1	2	3	4	5	6	7	8	9	10	11
No.*	Nominal Size of Screw Thread: B.S.W. and B.S.F.	Nominal Size of Screw Thread: B.A.	A	B	C	D	E	G	H	J
	in.		in.	in.	in.	in.	in.	in.	in.	in.
1	$\frac{1}{8}$	4 and 5	$\frac{5}{16}$	$\frac{13}{64}$	$\frac{1}{8}$	$\frac{11}{32}$	$\frac{21}{32}$	$\frac{13}{64}$	$\frac{3}{32}$	$\frac{3}{64}$
2	$\frac{3}{16}$	2 and 3	$\frac{27}{64}$	$\frac{15}{64}$	$\frac{11}{64}$	$\frac{7}{16}$	$\frac{27}{32}$	$\frac{17}{64}$	$\frac{1}{8}$	$\frac{5}{64}$
3	$\frac{1}{4}$	0 and 1	$\frac{31}{64}$	$\frac{5}{16}$	$\frac{13}{64}$	$\frac{1}{2}$	$1\frac{1}{16}$	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{3}{32}$
4	$\frac{5}{16}$	—	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{15}{64}$	$\frac{5}{8}$	$1\frac{7}{32}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{64}$
5	$\frac{3}{8}$	—	$\frac{43}{64}$	$\frac{15}{32}$	$\frac{17}{64}$	$\frac{23}{32}$	$1\frac{13}{32}$	$\frac{7}{16}$	$\frac{7}{32}$	$\frac{1}{8}$
6	$\frac{7}{16}$	—	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{29}{32}$	1[illegible]	$\frac{19}{32}$	$\frac{19}{64}$	$\frac{11}{64}$
7	$\frac{1}{2}$	—	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{29}{32}$	1[illegible]	$\frac{19}{32}$	$\frac{19}{64}$	$\frac{11}{64}$
8	$\frac{5}{8}$	—	$1\frac{5}{32}$	$\frac{7}{8}$	$\frac{17}{32}$	$1\frac{3}{8}$	$2\frac{11}{16}$	[illegible]	[illegible]	$\frac{3}{16}$
9	$\frac{3}{4}$	—	$1\frac{5}{32}$	$\frac{7}{8}$	$\frac{17}{32}$	$1\frac{3}{8}$	$2\frac{11}{16}$	[illegible]	[illegible]	$\frac{3}{16}$

* The numbers given in this column are the customary trade designations for the sizes of the nut blanks.

AMERICAN STANDARD PIPE THREAD (FORMERLY BRIGGS)

Nominal Size		A		B		E		F		D		Depth of Thread		Number of Threads	
in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	in.	mm.	per in.	per 254 mm.
1/8	3	0·36351	9·233	0·37476	9·519	0·2638	6·700	0·180	4·572	0·405	10·287	0 02963	0·753	27	270
1/4	6	0·47739	12·126	0·48989	12·443	0·4018	10·206	0·200	5·080	0·540	13·716	0·04444	1·129	18	180
3/8	10	0·61201	15·545	0·62701	15·926	0·4078	10·358	0·240	6·096	0·675	17·145	0·04444	1·129	18	180
1/2	13	0·75843	19·264	0·77843	19·772	0·5337	13·556	0·320	8·128	0·840	21·336	0·05714	1·451	14	140
3/4	19	0·96768	24·579	0·98886	25·117	0·5457	13·861	0·339	8·611	1·050	26·670	0·05714	1·451	14	140
1	25	1·21363	30·826	1·23863	31·461	0·6828	17·343	0·400	10·160	1·315	33·401	0·06956	1·767	11½	115
1¼	32	1·55713	39·551	1·58338	40·218	0·7068	17·953	0·420	10·668	1·660	42·164	0·06956	1·767	11½	115
1½	38	1·79609	45·621	1·82234	46·287	0·7235	18·377	0·420	10·668	1·900	48·260	0·06956	1·767	11½	115
2	50	2·26902	57·633	2·29627	58·325	0·7565	19·215	0·436	11·074	2·375	60·235	0·06956	1·767	11½	115
2½	64	2·71953	69·076	2·76216	70·159	1·1375	28·892	0·682	17·323	2·875	72·025	0·10000	2·540	8	80
3	76	3·34063	84·852	3·38850	86·068	1·2000	30·480	0·766	19·456	3·500	88·900	0·10000	2·540	8	80
3½	90	3·83750	97·473	3·88881	98·776	1·2500	31·750	0·821	20·853	4·000	101·600	0·10000	2·540	8	80
4	100	4·33438	110·093	4·38713	111·433	1·3000	33·020	0·844	21·438	4·500	114·300	0·10000	2·540	8	80
4½	113	4·83125	122·714	4·88594	124·103	1·3500	34·290	0·875	22·225	5·000	127·000	0·10000	2·540	8	80
5	125	5·39073	136·925	5·44929	138·412	1·4063	35·720	0·937	23·800	5·563	141·300	0·10000	2·540	8	80
6	150	6·44609	163·731	6·50597	165·252	1·5125	38·417	0·958	24·333	6·625	168·275	0·10000	2·540	8	80
7	175	7·43984	188·972	7·50234	190·560	1·6125	40·957	1·000	25·400	7·625	193·675	0·10000	2·540	8	80
8	200	8·43359	214·214	8·50003	215·901	1·7125	43·947	1·063	27·000	8·625	219·075	0·10000	2·540	8	80
9	225	9·42734	239·455	9·49797	241·249	1·8125	46·037	1·130	28·702	9·625	244·475	0·10000	2 540	8	80
10	250	10·54531	267·851	10·62094	269·772	1·9250	48·895	1·210	30·734	10·750	273·050	0·10000	2·540	8	80
11	275	11·53906	293·093	11·61938	295·133	2·0250	51·435	1·285	32·639	11·750	298·450	0·10000	2·540	8	80
12	300	12·53281	318·334	12·61781	320·493	2·1250	53·975	1·360	34·544	12·750	323·851	0·10000	2·540	8	80
14 O.D.	350	13·77500	349·886	13·87262	352·365	2·250	57·150	1·562	39·675	14·000	355·601	0·10000	2·540	8	80
15 O.D.	375	14·76875	375·127	14·87419	377·805	2·350	59·690	1·687	42·850	15·000	381·001	0·10000	2·540	8	80
16 O.D.	400	15·76250	400·368	15·87575	403·245	2·450	62·230	1·812	46·025	16·000	406·401	0·10000	2·540	8	80
17 O.D.	425	16·75625	425·609	16·87500	428·626	2·550	64·770	1·900	48·260	17·000	431·801	0·10000	2·540	8	80
18 O.D.	450	17·75000	450·851	17·87500	454·026	2·650	67·310	2·000	50·800	18·000	457·201	0·10000	2·540	8	80
20 O.D.	500	19·73750	501·333	19·87031	504·707	2·850	72·390	2·125	53·975	20·000	508·001	0·10000	2·540	8	80
22 O.D.	550	21·72500	551·816	21·86562	555·388	2·050	77·470	2·250	57·150	22·000	558·801	0·10000	2·540	8	80
24 O.D.	600	23·71250	602·299	23·86094	606·069	3·250	82·550	2·375	60·325	24·000	609·601	0·10000	2·540	8	80
26 O.D.	650	25·70000	652·781	25·85625	656·750	3·450	87·630	2·500	63·500	26·000	660·401	0·10000	2·540	8	80
28 O.D.	700	27·68750	703·264	27·85156	707·431	3·650	92·710	2·625	66·675	28·000	711·201	0·10000	2·540	8	80
30 O.D.	750	29·67500	753·746	29·84687	758·112	3·850	97·790	2·750	69·850	30·000	762·001	0·10000	2·540	8	80

Proportions of Briggs Pipe Thread

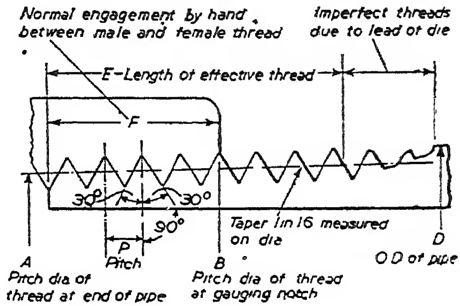
(See Table on page 624)

$A = D - (0{\cdot}05\,D + 1{\cdot}1)\,P$

$B = A + 0{\cdot}0625\,F$

$E = P\,(0{\cdot}8\,D + 6{\cdot}8)$

Depth of Thread $= 0{\cdot}8$ P.



WHITWORTH STANDARD SCREWS FOR INSTRUMENT AND WATCH MAKERS

No. denoting Thousandths of an inch in diameter	Threads per inch	No. denoting Thousandths of an inch in diameter	Threads per inch
10	400	34	150
11	400	36	150
12	350	38	120
13	350	40	120
14	300	45	120
15	300	50	100
16	300	55	100
17	250	60	100
18 and 19	250	65	80
20	210	70	80
22	210	75	80
24	210	80	60
26	180	85	60
28	180	90	60
30	180	95	50
32	180	100	50

A.S.M.E. STANDARD THREADS

(Formula same as U.S. Standard)

$$p = \text{pitch} = \frac{1}{\text{No. threads per in.}} \qquad d = \text{depth} = p \times 0{\cdot}64952 \qquad f = \text{flat} = \frac{p}{8}$$

Nominal Size and Threads per in.	Outside Diameter, in.	Pitch Diameter, in.	Root Diameter, in.	Tap Drill Size
0–80	·0600	·0519	·0438	56
1–56	·0730	·0614	·0498	55
64	·0730	·0629	·0527	54
72	·0730	·0640	·0550	53
2–56	·0860	·0744	·0628	51
64	·0860	·0759	·0657	50
3–48	·0990	·0855	·0719	48
56	·0990	·0874	·0758	47
4–32	·1120	·0917	·0714	48
36	·1120	·0940	·0759	46
40	·1120	·0958	·0795	45
48	·1120	·0985	·0849	43
5–36	·1250	·1078	·0889	42
40	·1250	·1088	·0925	40
44	·1250	·1102	·0955	39
6–32	·1380	·1777	·0974	38
36	·1380	·1200	·1019	36
40	·1380	·1218	·1055	35
7–30	·1510	·1294	·1077	33
32	·1510	·1307	·1104	32
36	·1510	·1330	·1149	31
8–30	·1640	·1423	·1207	30
32	·1640	·1437	·1234	30
36	·1640	·1460	·1279	29
40	·1640	·1478	·1315	29
9–24	·1770	·1499	·1229	30
30	·1770	·1553	·1337	29
32	·1770	·1567	·1364	28
10–24	·1900	·1629	·1359	28
28	·1900	·1668	·1436	26

A.S.M.E. STANDARD THREADS—*continued*

Nominal Size and Threads per in.	Outside Diameter, in.	Pitch Diameter, in.	Root Diameter, in.	Tap Drill Size
30	·1900	·1684	·1476	24
32	·1900	·1697	·1494	23
12–24	·2160	·1889	·1619	19
28	·2160	·1928	·1696	17
32	·2160	·1957	·1754	16
14–20	·2420	·2095	·1770	14
24	·2420	·2149	·1879	10
16–18	·2680	·2319	·1966	8
20	·2680	·2355	·2030	4
22	·2680	·2385	·2090	3
18–18	·2940	·2579	·2218	1
20	·2940	·2615	·2290	A
20–16	·3200	·2794	·2388	C
18	·3200	·2839	·2478	F
20	·3200	·2875	·2500	G
22–16	·3460	·3054	·2648	$\frac{9}{32}$
18	·3460	·3099	·2738	L
24–16	·3720	·3314	·2908	M
18	·3720	·3350	·2998	N
26–14	·3980	·3516	·3052	O
16	·3980	·3574	·3168	P
28–14	·4240	·3776	·3312	R
16	·4240	·3834	·3428	S
30–14	·4500	·4036	·3572	U
16	·4500	·4094	·3688	V

LETTER SIZES OF DRILLS

	in.		in.		in.		in.		in.
A	·234	G	·261	L	·290	Q	·332	V	·377
B	·238	H	·266	M	·295	R	·339	W	·386
C	·242	I	·272	N	·302	S	·348	X	·397
D	·246	J	·277	O	·316	T	·358	Y	·404
E	·250	K	·281	P	·323	U	·368	Z	·413
F	·257								

UNITED STATES STANDARD FORM THREAD

Including S.A.E. Standard

$$\text{Formula}\begin{cases} p=\text{pitch}=\dfrac{1}{\text{No. threads per in.}} \\ d=\text{depth}=p\times\cdot 64952 \\ f=\text{flat}\ =\dfrac{p}{8} \end{cases}$$

Diam., in.	Threads per Inch			Outside Dia-meter, in.	Pitch Dia-meter, in.	Root Dia-meter, in.	Tap Drill Size
	U.S. Std.	S.A.E. Std.	U.S. Form				
$\frac{1}{16}$	—	—	60	·0625	·0517	·0409	57
$\frac{1}{16}$	64	—	—	·0625	·0524	·0422	56
$\frac{1}{16}$	—	—	72	·0625	·0535	·0445	55
$\frac{5}{64}$	—	—	56	·0781	·0665	·0549	53
$\frac{5}{64}$	60	—	—	·0781	·0673	·0565	53
$\frac{3}{32}$	—	—	48	·0938	·0803	·0667	50
$\frac{3}{32}$	50	—	—	·0938	·0808	·0678	50
$\frac{3}{32}$	—	—	56	·0938	·0821	·0706	49
$\frac{3}{32}$	—	—	60	·0938	·0829	·0721	48
$\frac{7}{64}$	48	—	—	·1094	·0959	·0823	44
$\frac{1}{8}$	—	—	32	·1250	·1047	·0844	43
$\frac{1}{8}$	—	—	36	·1250	·1070	·0889	42
$\frac{1}{8}$	40	—	—	·1250	·1088	·0925	41
$\frac{1}{8}$	—	—	48	·1250	·1115	·0979	39
$\frac{9}{64}$	—	—	32	·1406	·1203	·1000	37
$\frac{9}{64}$	—	—	36	·1406	·1226	·1045	35
$\frac{9}{64}$	40	—	—	·1406	·1244	·1081	34
$\frac{5}{32}$	—	—	32	·1563	·1360	·1157	31
$\frac{5}{32}$	36	—	—	·1563	·1382	·1202	$\frac{1}{8}$
$\frac{5}{32}$	—	—	40	·1563	·1400	·1238	30
$\frac{11}{64}$	32	—	—	·1719	·1505	·1313	29
$\frac{11}{64}$	—	—	36	·1719	·1538	·1358	28
$\frac{3}{16}$	24	—	—	·1875	·1604	·1334	29
$\frac{3}{16}$	—	—	30	·1875	·1658	·1442	26
$\frac{3}{16}$	—	—	32	·1875	·1672	·1469	25
$\frac{3}{16}$	—	—	36	·1875	·1695	·1514	23
$\frac{13}{64}$	24	—	—	·2031	·1760	·1490	24

UNITED STATES STANDARD FORM THREAD—*continued*

Including S.A.E. Standard

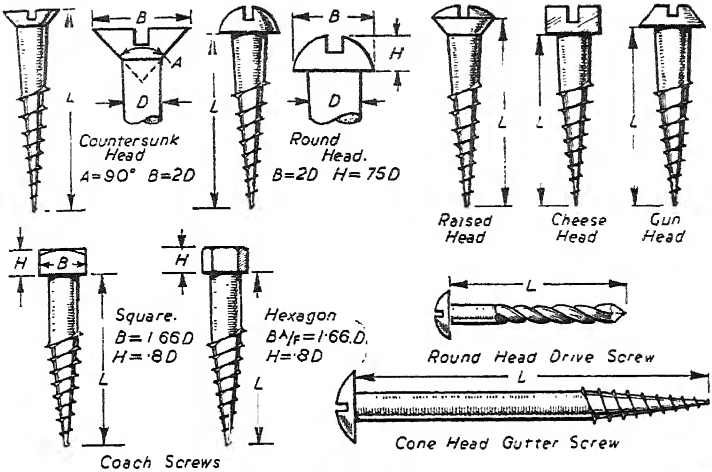
Diam., in.	Threads per Inch			Outside Dia-meter, in.	Pitch Dia-meter, in.	Root Dia-meter, in.	Tap Drill Size
	U.S. Std.	S.A.E. Std.	U.S. Form				
$\frac{13}{64}$	—	—	32	·2031	·1828	·1625	19
$\frac{7}{32}$	24	—	—	·2188	·1916	·1646	19
$\frac{7}{32}$	—	—	28	·2188	·1956	·1724	16
$\frac{7}{32}$	—	—	32	·2188	·1985	·1782	14
$\frac{15}{64}$	24	—	—	·2344	·2073	·1806	13
$\frac{15}{64}$	—	—	28	·2344	·2112	·1880	10
$\frac{15}{64}$	—	—	32	·2344	·2141	·1942	8
$\frac{1}{4}$	20	—	—	·2500	·2176	·1850	12
$\frac{1}{4}$	—	—	24	·2500	·2229	·1959	7
$\frac{1}{4}$	—	28	—	·2500	·2268	·2306	4
$\frac{1}{4}$	—	—	32	·2500	·2297	·2094	3
$\frac{5}{16}$	18	—	—	·3125	·2764	·2403	D
$\frac{5}{16}$	—	—	20	·3125	·2800	·2476	E
$\frac{5}{16}$	—	24	—	·3125	·2854	·2584	G
$\frac{5}{16}$	—	—	32	·3125	·2922	·2719	J
$\frac{3}{8}$	16	—	—	·3750	·3344	·2938	N
$\frac{3}{8}$	—	—	18	·3750	·3389	·3029	$\frac{5}{16}$
$\frac{3}{8}$	—	—	20	·3750	·3425	·3100	P
$\frac{3}{8}$	—	24	—	·3750	·3479	·3209	Q
$\frac{7}{16}$	14	—	—	·4375	·3911	·3447	S
$\frac{7}{16}$	—	20	—	·4375	·4050	·3726	V
$\frac{7}{16}$	—	—	24	·4375	·4104	·3834	X
$\frac{1}{2}$	—	—	12	·5000	·4459	·3918	Y
$\frac{1}{2}$	13	—	—	·5000	·4501	·4001	$\frac{13}{32}$
$\frac{1}{2}$	—	20	—	·5000	·4675	·4351	$\frac{29}{64}$
$\frac{1}{2}$	—	—	24	·5000	·4729	·4459	$\frac{29}{64}$
$\frac{9}{16}$	12	—	—	·5625	·5084	·4542	$\frac{15}{32}$
$\frac{9}{16}$	—	18	—	·5625	·5264	·4903	$\frac{1}{2}$
$\frac{5}{8}$	11	—	—	·6250	·5660	·5069	$\frac{33}{64}$
$\frac{5}{8}$	—	—	12	·6250	·5709	·5168	$\frac{17}{32}$
$\frac{5}{8}$	—	18	—	·6250	·5889	·5528	$\frac{9}{16}$
$\frac{11}{16}$	11	—	—	·6875	·6285	·5694	$\frac{37}{64}$
$\frac{11}{16}$	—	—	12	·6875	·6334	·5793	$\frac{19}{32}$
$\frac{11}{16}$	—	16	—	·6875	·6469	·6063	$\frac{39}{64}$
$\frac{3}{4}$	10	—	—	·7500	·6851	·6201	$\frac{5}{8}$
$\frac{3}{4}$	—	—	12	·7500	·6959	·6418	$\frac{21}{32}$
$\frac{3}{4}$	—	16	—	·7500	·7094	·6688	$\frac{43}{64}$

WOOD-SCREW PROPORTIONS

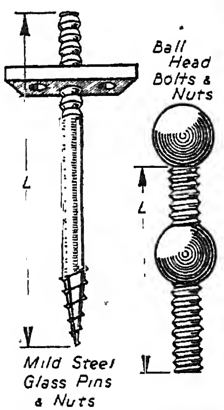
No. (or size) of Screw	Diameter of Neck or Shank	For Wood or Metal			With Side Lips and Centre for Wood only	
			No., etc.	Diameter	Size	Diameter
1	·066	Stub's Wire Gauge Drills.	51	·067	—	—
2	·080		46	·081	—	—
3	·094		41	·096	—	—
4	·108		35	·110	—	—
5	·122		30	·128	$\frac{1}{8}$	·125
6	·136		28	·140	—	—
7	·150		23	·154	$\frac{5}{32}$	·156
8	·164		18	·169	—	—
9	·178		14	·182	$\frac{3}{16}$	·187
10	·192		9	·196	—	—
11	·206		4	·209	$\frac{7}{32}$	·218
12	·220		1	·228	—	—
13	·234	Letter Gauge Drills.	B	·238	—	—
14	·248		E	·250	$\frac{1}{4}$	·250
15	·262		H	·266	—	—
16	·276		K	·281	$\frac{9}{32}$	·281
17	·290		M	·295	—	—
18	·304		O	·316	$\frac{5}{16}$	·312
19	·318		P	·323	—	—
20	·332		R	·339	$\frac{11}{32}$	·343
21	·346		S T	·348 ·358	—	—
22	·360		U	·368	$\frac{3}{8}$	·375
23	·374		V	·377	$\frac{3}{8}$	·375
24	·388		X	·397	—	—
25	·402		Z	·413	$\frac{13}{32}$	·406
26	·416		$\frac{27}{64}$	·421	—	—
27	·430		$\frac{7}{16}$	·437	$\frac{7}{16}$	·437
28	·444		$\frac{29}{64}$	·453	—	—
29	·458		$\frac{15}{32}$	·468	$\frac{15}{32}$	·468
30	·472		$\frac{31}{64}$	·484	—	—
31	·486		$\frac{1}{2}$	·500	$\frac{1}{2}$	·500
32	·500		$\frac{33}{64}$	·515	$\frac{1}{2}$	·500

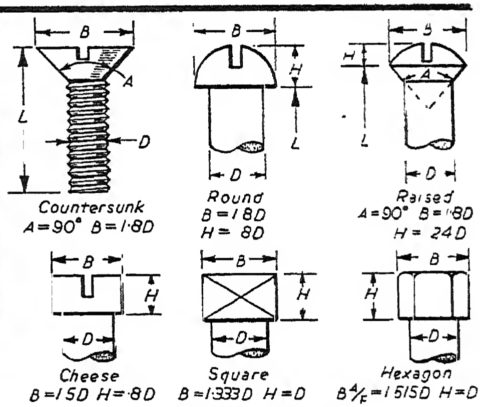
All dimensions in parts of an inch.

(Refer to Diagrams on page 631)

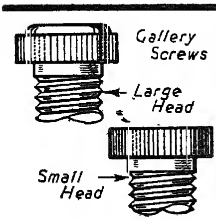


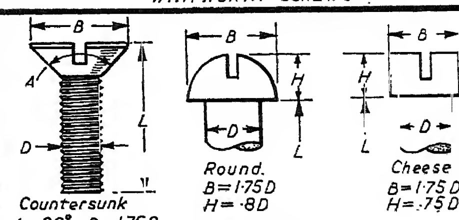
WOOD SCREWS





WHITWORTH SCREWS





B. A. SCREWS

HOLTZAPFFEL'S THREADS

(Obsolescent)

External Diameter, inches	Letters	Nos.	Thread-turns per inch	Pitch of Thread	Change-wheels with Guide Screw of $\frac{1}{4}$-in. pitch
1·000	A	1	6·58	$\left\{\frac{5}{329}\right\}$	$\left\{\begin{matrix}50\times40\\70\times47\end{matrix}\right.$
·875 = $\frac{7}{8}$	B	2	8·25	$\left\{\frac{4}{33}\right\}$	$\left\{\begin{matrix}48\times80\\60\times110\end{matrix}\right.$
·750 = $\frac{3}{4}$	C	3	9·45	$\left\{\frac{20}{189}\right\}$	$\left\{\begin{matrix}50\times80\\90\times105\end{matrix}\right.$
·625 = $\frac{5}{8}$ ·560 ·500 = $\frac{1}{2}$	DD D E	4	13·09	$\left\{\frac{100}{1309}\right\}$	$\left\{\begin{matrix}20\times100\times50\\70\times55\times85\end{matrix}\right.$
·450	F	5	16·5	$\left\{\frac{2}{33}\right\}$	$\left\{\begin{matrix}40\times80\\110\times120\end{matrix}\right.$
·410 ·360	G H	6	19·89	$\left\{\frac{100}{1989}\right\}$	$\left\{\begin{matrix}20\times50\times100\\65\times85\times90\end{matrix}\right.$
		7	22·1	$\left\{\frac{10}{221}\right\}$	$\left\{\begin{matrix}25\times40\\65\times85\end{matrix}\right.$
·330 ·290 ·250 $\frac{1}{4}$	I J K	8	25·65	$\left\{\frac{20}{513}\right\}$	$\left\{\begin{matrix}20\times100\\95\times135\end{matrix}\right.$
·210	L	9	28·9	$\left\{\frac{25}{722}\right\}$	$\left\{\begin{matrix}20\times50\\85\times85\end{matrix}\right.$
·240 ·200 = $\frac{1}{5}$ ·180	M N O	10	36·1	$\left\{\frac{10}{361}\right\}$	$\left\{\begin{matrix}25\times40\\95\times95\end{matrix}\right.$
·190 ·162	P Q	11	39·9	$\left\{\frac{10}{399}\right\}$	$\left\{\begin{matrix}25\times40\\95\times105\end{matrix}\right.$
·150 ·135 ·120 ·100 = $\frac{1}{10}$	R S T U	12	55·	$\left\{\frac{1}{55}\right\}$	$\left\{\begin{matrix}20\times40\\100\times110\end{matrix}\right.$

Basic Principles.—The peripheral speed of cutting tools relative to the work-piece is dependent upon the material of the work-piece and the cutting angle of the cutting tool.

The speed is also governed by the material of which the cutting tool is made, this being determined by the "Red Hardness" of that particular material.

Thus for cutting tools made from a particular material, e.g. high-speed steel, maximum peripheral speeds for different work-piece material are imposed with a corresponding regulation of the cutting rake to be employed.

In the case of tungsten carbide the nature of the material, i.e. weak in tension but strong in pressure, also imposes a minimum top rake for different work-piece materials, thus imposing a minimum speed of work-piece, in addition to the above-mentioned maximum limit.

The feed is determined by limitation of chip flow, strength of cutting tool, power available, and presence or absence of lubricant or coolant.

Minimum feed is determined by the sharpness of the tool (dependent upon the material from which the tool is made and the method of sharpening).

Turning.—In turning generally the continuous nature of the cut with absence of shock load enables generous top rakes to be employed in conjunction with ample lubrication and coolant, so that high chip thicknesses can be used at an efficient speed from a power consideration.

TABLE I

RAKE AND RELIEF ANGLES FOR HIGH-SPEED STEEL TOOLS CUTTING VARIOUS METALS

Material	*Operation*	*Top Rake (deg.)*	*Side Rake (deg.)*	*Side Clearance (deg.)*	*End Clearance (deg.)*
Soft steel	Roughing	6–10	14–22	5–9	5–9
	Finishing	14–22	0	0	5–9
Hard steel	Roughing	4–8	10–14	5–9	5–9
	Finishing	8–14	0	0	5–9
Very hard steel ..	Roughing	3–7	5–10	5–9	5–9
	Finishing	5–10	0	0	5–9
Cast iron	Roughing	8	14	5–9	5–9
	Finishing	6–10	0	0	5–9
Brass bronze ..	Roughing	6–8	4–10	5–9	5–9
	Finishing	14–22	0	0	5–9
Copper	Roughing	8–12	16–28	5–9	5–9
	Finishing	8	16–28	0	5–9
Monel metal ..	Roughing	4–8	10–14	5–9	5–9
	Finishing	14–22	0	0	5–9
Aluminium	Roughing	8	16–22	5–9	5–9
	Finishing	8	16–22	0	5–9
Magnesium alloys ..	Roughing	5–8	3–5	6–10	6–10
	Finishing	10–15	0	0	6–10

Table II

Speeds and Feeds for Tungsten Carbide-tipped Turning Tools

Material	*Feet per Minute*	*Clearance (deg.)*	*Top Rake (deg.)*
Steel			
28–35 tons tensile:			
Clean metal	300–1,200	4–6	8
Castings	300–750	4–6	0–3½
Rough forgings—removing scale	300–400	4–6	0–3½
Black bar, stampings	300–750	4–6	0
35–45 tons tensile:			
Clean metal	300–1,200	4–6	8–13
Castings	250–500	4–6	0–3½
Rough forgings—removing scale	300–400	4–6	0–3½
Black bar, stampings	300–750	4–6	3½
45–55 tons tensile:			
Clean metal	300–750	4–6	3½
Castings	200–350	4–6	0
Rough forgings—removing scale	200–300	4–6	0–3½
Black bar, stampings	250–750	4–6	0–3½
55–65 tons tensile:			
Clean metal	300–1,000	4–6	0–3½
Rough forgings—removing scale	200–300	4–6	0–3½
Black bar, stampings	250–750	4–6	0–3½
High-speed steel—annealed	80–250	4–6	3½
Chrome nickel—65–90 tons tensile:			
Clean metal	250–1,000	4–6	0–3½
Forgings	80–350	4–6	0
Black bar, stampings	80–350	4–6	0
Stainless steel:			
Bar	100–300	4–6	3½
Castings	60–150	4–6	0
Manganese steel—12 per cent.	10–40	4–6	0
Cast Iron and Wrought Iron			
Cast iron—grey	200–700	4–6	0
Centrifugal castings	120–350	4–6	3½
Chilled-iron rolls	10–50	4–6	0
Chromium iron	120–350	4–6	3½
Close-grained iron	150–400	4–6	3½
Malleable iron	100–450	4–6	8
10 per cent. nickel iron	20–45	4–6	0
Non-ferrous Metals			
Admiralty bronze	300–750	4–6	0–3½
Aluminium	1,000–2,000	4–6	13–16
Aluminium alloys	300–750	4–6	13–16
Aluminium bronze	300–750	4–6	0–3½
Bronze	400–1,000	4–6	0–3½
Soft brass	500–1,200	4–6	3½
Hard-cast brass	400–1,000	4–6	0
Copper	500–1,200	4–6	13–16
Cupro-nickel	350–500	4–6	3½
Duralumin	300–750	4–6	13–16
Gun-metal	400–1,000	4–6	0–3½
Manganese bronze	300–750	4–6	0
Silicon aluminium	300–750	4–6	13–16
Zinc-base alloys	300–750	4–6	13–16
Non-metallic Materials			
Ebonite	500–1,000	20	0
Glass	30–70	4–6	3½
Hard rubber	500–1,000	20	0
Plastics	500–1,000	20	0
Porcelain	10–65	4–6	0
Marble	10–65	4–6	0–3½
Slate	50–100	4–6	3½

TABLE III

CUTTING SPEEDS FOR TURNING WITH H.S.S. TOOLS

Material Cut	*Surface Speed (ft./min.)*	*Material Cut*	*Surface Speed (ft./min.)*
Alloy steel (containing nickel and chromium)	30–50	Mild steel (bright) ..	70–100
Cast iron	50	"Yellow" brass ..	200
Malleable iron	70	"Leaded" brass ..	200–400
Cast steel	60	Cast brass	150–250
Steel forging (0·15–0·2 per cent. carbon)	65	Bronze	30–80
Mild steel (black)	70	Aluminium alloy ..	200–800
		Magnesium alloy ..	200–800

TABLE IV

SHAPING MACHINE SURFACE SPEEDS

Cutting Speed (ft./min.)	*Number of Strokes per Min. for Stroke Length of—*					
	8 *in.*	10 *in.*	12 *in.*	15 *in.*	20 *in.*	30 *in.*
30	30	24	20	16	12	8
40	40	32	27	21	16	11
50	50	40	33	27	20	13
60	60	48	40	32	24	16
70	70	56	47	37	28	18
80	80	64	53	43	32	21
90	90	72	60	48	36	24
100	100	80	67	53	40	26
110	110	88	73	59	44	29
120	120	96	80	64	48	32
130	130	104	87	69	52	35
140	140	112	93	75	56	38
150	150	120	100	80	60	40
160	160	128	107	85	64	43

The above figures are average speeds assuming a return speed ratio of 2 : 1.

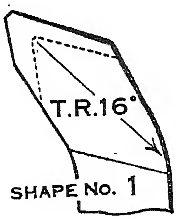


Fig. 1.—Light turning and facing. (Opp. hand No. 2.)

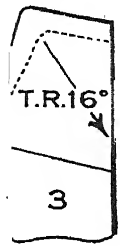


Fig. 2.—Straight-nosed rougher. (Opp. hand No. 4.)

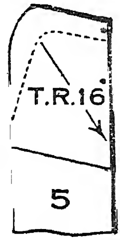


Fig. 3.—Curved-nosed rougher. (Opp. hand No. 6.)

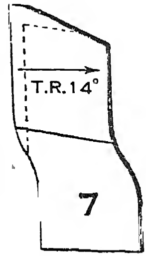


Fig. 4.—Knife or side cutting. (Opp. hand No. 8.)

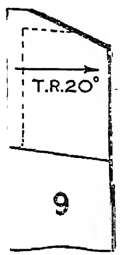


Fig. 5.—Bar turning.

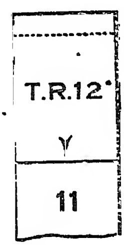


Fig. 6.—Plain form.

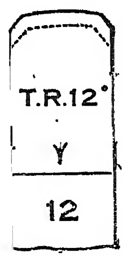


Fig. 7.—Finishing.

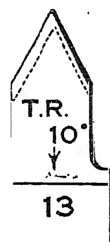


Fig. 8.—Internal screw cutting. (13 L.H. for L.H. Threads.)

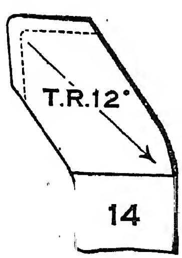


Fig. 9.—Down cutting and facing. (Opp. hand No. 15.)

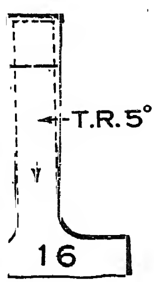


Fig. 10.—Parting off.

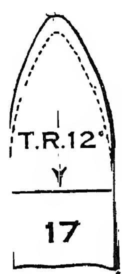


Fig. 11.—Round-nosed shaper or planer.

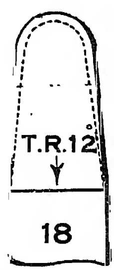


Fig. 12.—Stub-nosed planer or shaper.

Figs. 1 to 12.—Suitable shapes for lathe shaper and planer tools. Shape Nos. can be specified when ordering from most reputable manufacturers.

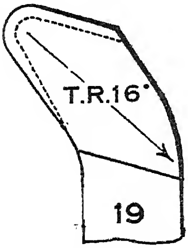


Fig. 13.—Facing. (Opp. hand No. 20.)

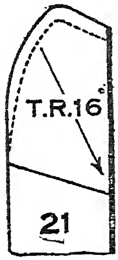


Fig. 14.—Round-nosed rougher. (Opp. hand No. 52.)

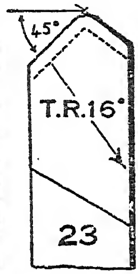


Fig. 15.—Heavy-duty turning. (Opp. hand No. 44.)

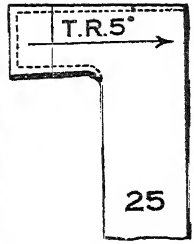


Fig. 16.—Right-angle recessing (Opp. hand No. 56.)

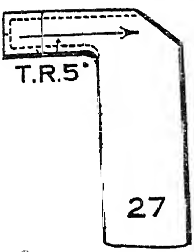


Fig. 17.—Right-angle parting tool. (Opp. hand No. 28.)

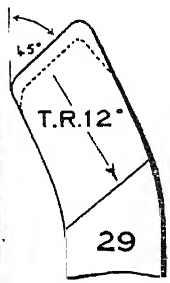


Fig. 18.—Square-nosed turning and facing. (Opp. hand No. 30.)

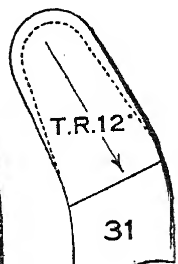


Fig. 19.—Broad-nosed facing. (Opp. hand No. 32.)

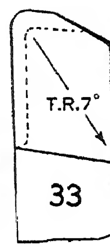


Fig. 20.—Turning and facing. (Opp. hand No. 34.)

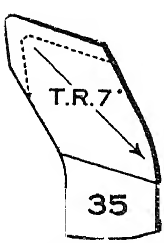


Fig. 21.—Light turning and facing. (Opp. hand No. 36.)

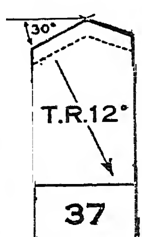


Fig. 22.—Straight rougher. (Opp. hand No. 38.)

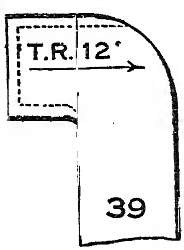


Fig. 23.—Crank turning. (Opp. hand No. 40.)

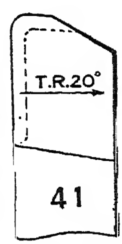


Fig. 24.—Mild-steel turning. (Opp. hand No. 42.)

Figs. 13 to 24.—Suitable shapes for lathe shaper and planer tools. Shape Nos. can be specified when ordering from most reputable manufacturers.

Feed per revolution in turning will vary from 0·001 in. per revolution for very fine finishes to 0·015 in. for general light engineering to $\frac{1}{8}$ in. or more for heavy engineering according to power available. Depth of cut will depend upon the particular application, i.e. reduction in diameter required and power available.

It is better to use one deep cut at fairly fine feed than several shallow cuts at coarse feed to remove the same bulk of material.

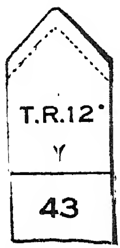


Fig. 25.—Diamond nosed.

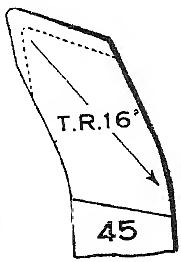


Fig. 26.—Light turning. (Opp. hand No. 46.)

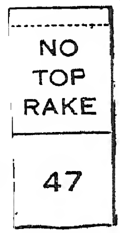


Fig. 27.—Blank.

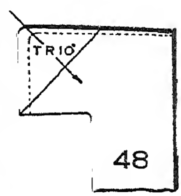


Fig. 28.—Bar boring. (Opp. hand No. 49.)

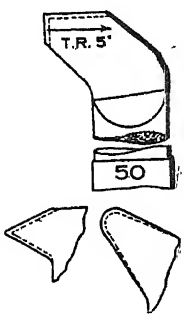


Fig. 29.—Boring.

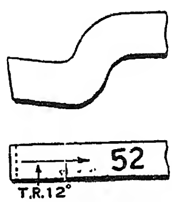


Fig. 30.—Swan-necked finisher.

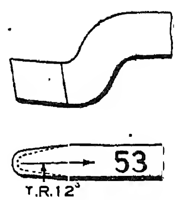


Fig. 31.—Swan-necked rougher.

Figs. 25 to 31.—Suitable shapes for lathe shaper and planer tools. Shape Nos. can be specified when ordering from most reputable manufacturers.

Planers and Shapers.—Planer and shaper tools have to be of a more robust construction to withstand shock load and so rake angles are less than usual turning-tool practice. Feeds are higher and surface speeds somewhat lower.

Drills.—The feed of a drill is limited by the torsional strength of the cutting tool and so feeds are somewhat fine. Owing to the difficulty of lubricating or cooling the drill point, surface speeds are not particularly high, but the excellent cutting action imparted by the helical flutes gives free-cutting qualities to the twist drills.

Taps.—Owing to the large tooth load which is necessarily imposed upon a tap, the speeds will be somewhat lower than for drills. This condition is also imposed by the high axial velocity imparted to taps owing to the feeds which correspond to the pitch of the tap. Lubricant should always be used in tapping, and recommendations are included in the table of Cutting Speeds for Taps.

TABLE V

CUTTING SPEEDS FOR PLANER AND SHAPER TOOLS

Material Cut	*Surface Speed (ft./min.)*
Alloy steel (containing nickel and chromium) ..	25–30
Cast iron	30–50
Malleable iron	30–60
Cast steel	30–40
Steel forging (0·15–0·2 per cent. carbon)	30–60
Mild steel (black)	30–65
Mild steel (bright)	40–70
"Yellow" brass	As fast as practicable
"Leaded" brass	As fast as practicable
Cast brass	As fast as practicable
Bronze	40–70

Dies.—The cutting conditions of dies are very similar to those appertaining to taps, and, in general, speeds are somewhat similar. A slight increase of speed (in the region of 10%) could be allowed as dies can be more efficiently lubricated and cooled with cutting fluid than can taps.

TABLE VI

SPEEDS FOR TAPPING WITH H.S.S. TAPS

Material to be Tapped	*Surface Speed (ft./min.)*	*Lubricant*
Mild steel	25	Animal lard oil, or tallow
Cast steel	20	
Alloy steel..	10–20	
Brass (rolled)	50	Soluble oil
Brass (cast)	70	
Aluminium alloy	100	Paraffin
Cast iron	20	

Table VII.—Cutting Speeds for Twist Drills

Cutting Speed (ft./min.)	50	60	70	80	90	100	150	200
Drill Diameter (in.)	*Revolutions per Minute*							
$\frac{1}{64}$	12,224	14,656	17,088	19,520	22,016	24,448	36,672	48,896
$\frac{1}{32}$	6,112	7,328	8,544	9,760	11,008	12,224	18,336	24,448
$\frac{3}{64}$	4,064	4,896	5,696	6,528	7,328	8,160	12,224	16,320
$\frac{1}{16}$	3,056	3,664	4,272	4,880	5,504	6,112	9,168	12,224
$\frac{5}{64}$	2,448	2,928	3,424	3,904	4,400	4,896	7,344	9,792
$\frac{3}{32}$	2,032	2,448	2,848	3,264	3,664	4,080	6,112	8,160
$\frac{7}{64}$	1,744	2,096	2,448	2,800	3,136	3,488	5,232	6,976
$\frac{1}{8}$	1,528	1,832	2,136	2,440	2,752	3,056	4,584	6,112
$\frac{5}{32}$	1,224	1,464	1,712	1,952	2,200	2,448	3,672	4,896
$\frac{3}{16}$	1,016	1,224	1,424	1,632	1,832	2,040	3,056	4,080
$\frac{7}{32}$	872	1,048	1,224	1,400	1,568	1,744	2,616	3,488
$\frac{1}{4}$	764	916	1,068	1,220	1,376	1,528	2,292	3,056
$\frac{9}{32}$	680	816	952	1,088	1,224	1,360	2,040	2,720
$\frac{5}{16}$	612	732	856	976	1,100	1,224	1,836	2,448
$\frac{11}{32}$	556	668	776	888	1,000	1,112	1,668	2,224
$\frac{3}{8}$	508	612	712	816	916	1,020	1,528	2,040
$\frac{7}{16}$	436	524	612	700	784	872	1,308	1,744
$\frac{1}{2}$	382	458	534	610	688	764	1,146	1,528
$\frac{9}{16}$	340	408	476	544	612	680	1,020	1,360
$\frac{5}{8}$	306	366	428	488	550	612	918	1,224
$\frac{11}{16}$	278	334	388	444	500	556	834	1,112
$\frac{3}{4}$	254	306	356	408	458	510	764	1,020
$\frac{13}{16}$	234	282	330	376	424	470	704	940
$\frac{7}{8}$	218	262	306	350	392	436	654	872
$\frac{15}{16}$	204	244	286	326	366	408	612	816
1	191	229	267	305	344	382	573	764
$1\frac{1}{8}$	170	204	238	272	306	340	510	680
$1\frac{1}{4}$	153	183	214	244	275	306	459	612
$1\frac{3}{8}$	139	167	194	222	250	278	417	556
$1\frac{1}{2}$	127	153	178	204	229	255	382	510
$1\frac{5}{8}$	117	141	165	188	212	235	352	470
$1\frac{3}{4}$	109	131	153	175	196	218	327	436
$1\frac{7}{8}$	102	122	143	163	183	204	306	408
2	95	114	133	152	172	191	286	382

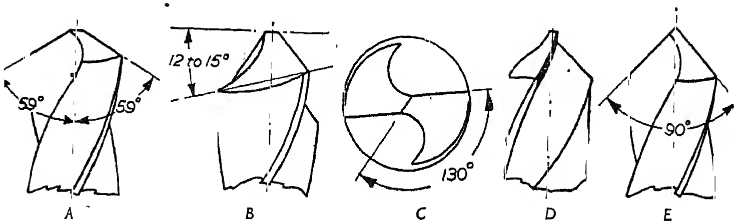
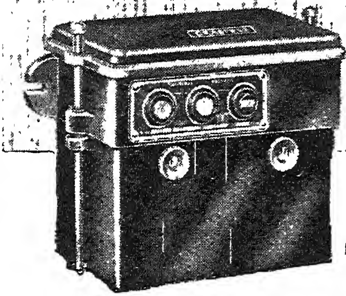


Fig. 32.—Types of drill points recommended for drilling different materials.

A, B, C } Normal standard drill point, for general use.
D "Lands" ground on flutes for brass.
E 90° point for wood or plastics.

CRABTREE AUTOMATIC CONTROL GEAR



Type "P.C.D.L." Switches

IN the Crabtree range of pole-changing, direct-on-line, triple-pole control switches, the engineer is offered three main types. Each fulfils the same primary function of providing a simple and convenient means of connection changing for multi-speed squirrel-cage motors. Each of the three types is designed to give a different number of speed connections to suit the individual motor windings.

The unit illustrated above is a P.C.D.L. 2-speed pattern and gives "Slow" and "Fast" speeds. Like the 3- and 4-speed patterns, this is magnetically operated and is controlled by means of coloured push-buttons surmounted by a metal indication plate. In all three types, again, mechanically operated visual "on" and "off" indication is provided, and no-volt protection is inherent. Remote control stations can, of course, be provided in all cases, while fusing and isolation arrangements are also available.

CRABTREE

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"Crabtree" (Registered) C.549 *Advt. of J. A. Crabtree & Co. Ltd., Walsall, England*

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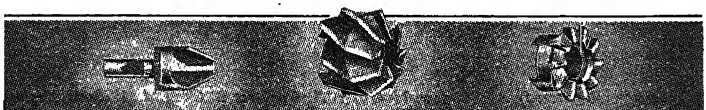


TABLE VIII

SPEEDS AND FEEDS FOR HIGH-SPEED STEEL TWIST DRILLS

Material	*Speed (ft./min.) (according to relative hardness of material)*	*Drill Diameter (in.)*	*Feed per Revolution (in.)*
Free cutting steels	150–250	$\frac{1}{16}$–$\frac{3}{32}$	0·0015–0·0025
Aluminium and brass	100–200	$\frac{1}{8}$–$\frac{5}{32}$	0·002 –0·004
Cast iron :		$\frac{3}{16}$–$\frac{7}{32}$	0·003 –0·006
(*a*) Medium	80–100		
(*b*) Hard	50– 70	$\frac{1}{4}$–$\frac{5}{16}$	0·004 –0·008
Mild, structural and tool steels :		$\frac{3}{8}$–$\frac{7}{16}$	0·006 –0·010
(*a*) Up to 0·40° C.	80–100		
(*b*) 0·45° to 0·70° C.	60– 80	$\frac{1}{2}$–$\frac{9}{16}$	0·008 –0·012
(*c*) 0·75° C. and up	40– 60		
		$\frac{5}{8}$–$\frac{11}{16}$	0·009 –0·013
Alloy steels :			
(*a*) Up to 60 tons tensile . .	50– 70	$\frac{3}{4}$–$\frac{13}{16}$	0·010 –0·014
(*b*) 60 to 80 tons tensile . .	30– 50		
(*c*) Over 80 tons tensile . .	15– 30	$\frac{7}{8}$–$\frac{15}{16}$	0·011 –0·015
Stainless steels :		1 –1$\frac{1}{8}$	0·012 –0·016
(*a*) Magnetic			
(*b*) Non-magnetic	40– 60	1$\frac{1}{4}$–1$\frac{1}{2}$	0·014 –0·018
	20– 50		
		Over 1$\frac{1}{2}$	0·016 –0·020*

Note.—On new work commence at slowest appropriate speed and lightest feed and gradually increase until optimum output per grind is obtained.

* Or greater according to work.

Sawing : Power Hacksaws.—The cutting speed of a hacksaw naturally depends upon the material being cut. The feed of a hacksaw is usually obtained by means of pressure across the blade. The combination of the pressure and number of teeth per inch determines the rate of feed. For soft materials coarse-pitch teeth and light pressure are required, and for hard materials fine-pitch teeth and high pressure. For fine sections such as tubing, a large number of teeth are required so that some teeth are in constant contact with the section to avoid snatching.

Flexible-back Metal-cutting Bandsaws.—The speeds and feeds of bandsaws are regulated in a similar manner to that for power hacksaws, but bandsaws have the advantage of a longer time inactive after a relatively short-time cutting for each particular tooth. This allows higher peripheral speeds.

Milling Saws.—With milling saws the feed per tooth is dependent upon the ability of the teeth to clear themselves, and also is dependent upon the tendency to wander. Too high a feed will cause such wandering, even should the teeth be of sufficient size to prevent clogging.

Inserted Tooth Circular Metal Bandsaws.—In general the feeds depend a great deal on the hardness of the stock to be cut, which means the harder the stock to be cut the slower the feed. The feeds given in this instance are in square

inches per minute, and in order to convert this to table feed inches per minute the following rule naturally applies:

Square inches per minute divided by depth of section equals inches per minute feed.

TABLE IX

SPEEDS AND FEEDS FOR POWER HACKSAW BLADES

Material	*Number of Teeth per Inch*	*Strokes per Min.*	*Pounds Pressure*
Aluminium	4–6	135–150	60
Brass, cast (soft)..	6–10	135–150	60
Brass, cast (hard)	6–10	135	60
Cast iron	6–10	135	120
Copper	6–10	135	120
Tool steel	4–6–10	90	120
Cold-rolled steel	4–6	135	150
High-speed steel	6–10	90	120
Machine steel	4–6	135	150
Iron pipe	10–14	135	120
Structural steel	6–10	135	120
Tubing, steel	14	135	60
Tubing, brass	14	135	60

TABLE X

WIDTH OF SAW FOR CUTTING RADIUS

Width of Bandsaw (in.)	*Minimum Radius Cut (in.)*	*Width of Bandsaw (in.)*	*Minimum Radius Cut (in.)*
$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{8}$	$1\frac{1}{2}$
$\frac{3}{32}$	$\frac{3}{16}$	$\frac{1}{2}$	$2\frac{1}{4}$
$\frac{1}{8}$	$\frac{1}{4}$	$\frac{5}{8}$	3
$\frac{3}{16}$	$\frac{7}{16}$	$\frac{3}{4}$	$4\frac{1}{2}$
$\frac{1}{4}$	$\frac{3}{4}$	1	8

Table XI

Speeds and Feeds for Flexible-back Bandsaws

RECOMMENDED SPECIFICATIONS FOR CUTTING SPECIFIC MATERIALS WITH HARD-EDGE FLEXIBLE-BACK METAL-CUTTING BANDSAWS

Material	*No. of Teeth per Inch*	*Speed of Blade (ft./min.)*	*Material*	*No. of Teeth per Inch*	*Speed of Blade (ft./min.)*
Aluminium:			Hose—metallic	18–24	250–500
Solids	8–10	800–2,500	Inconel	10–12	70–90
Sheets	8–10	1,000–3,000	Iron bars	12–14	100–125
Aluminium alloys:			Iron sheets (under $\frac{1}{32}$ in.)	14–18	100–250
Solids	8–10	100–150			
Irregular shapes	12–14	200–300	Metal-faced wood	12–14	300–750
Asbestos sheets	8–12	150–200	Mica	10–12	300–600
Babbit	10–14	1,000–1,500	Micarta	8	300–500
Bakelite	8–10	800–1,000	Monel metal	10–12	100–150
Brass castings:			Nickel silver	18–24	100–150
Soft	10–14	700–1,500	Pipe	14–18	100–200
Hard	10–14	200–500	Radiator core	18–24	150–400
Brass sheets and tubing	14–18	700–1,500	Rubber—hard	10–14	150–200
			Slate	10–14	100–150
Bronze:			Steel:		
Bars	10–14	150–350	Chromium	12–14	90–125
Castings	10–14	300–800	Cold rolled	10–12	100–125
Mouldings	14–18	500–1,000	Drill rod	14	100–125
Cast iron	12–14	100–125	Heat-resistant	12–14	90–125
Catalin	12–14	700–800	High-speed	12–14	90–125
Copper	8–12	500–1,000	Machinery	10–14	100–125
Copper-nickel	12–14	70–90	Manganese	10–12	90–100
Everbright	10–12	150–350	Nickel	10–14	90–125
Everdue	10–12	150–350	Structural	10–14	90–125
Fibre	8–10	300–500	Tool	12–14	100–125
Formica	8	300–500	Tubing	14–18	100–150
Hose—canvas and rubber	8–10	500–1,000	Textolite	8	300–500
			Transite	8–12	100–200

Table XII

Dimensions and Radius

Width of Saw (in.)	*Points to Inch*	*Minimum Radius Can Cut (in.)*	*Width of Saw (in.)*	*Points to Inch*	*Minimum Radius Can Cut (in.)*
$\frac{1}{8}$	7	$\frac{3}{8}$	$\frac{3}{4}$	4	$4\frac{1}{2}$
$\frac{3}{16}$	7	$\frac{1}{2}$	$\frac{7}{8}$	4	6
$\frac{1}{4}$	7	$\frac{3}{4}$	1	4	8
$\frac{3}{8}$	6	$1\frac{1}{2}$	$1\frac{1}{4}$	3	12
$\frac{1}{2}$	5	$2\frac{1}{4}$	$1\frac{1}{2}$	5	20
$\frac{5}{8}$	5	3			

TABLE XIII

NARROW PLASTIC AND WOOD-CUTTING BANDSAWS

GAUGE OF SAW TO SIZE OF WHEEL

Size of wheel (in.):	12	16	18	20	24	30	36	42
Gauge of saw:	26	24	24	22	22	22	21	20

BANDSAW TENSION OR STRAIN

Width of blade (in.):	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{2}$
Tension in pounds:	25	55	100	160	200	240	280	320	440

TABLE XIV

SPEEDS AND FEEDS FOR MILLING SAWS

(Circular—High Temper)

Material to be Cut	*Saw Arbor above Work*		*Saw Arbor below Work*		*Rim Speed in Feet per Min.*	*Feed in Inches per Min.*
	Style Tooth	*Hook Angle*	*Style Tooth*	*Hook Angle*		
Steel (tool and alloy)	5	Rad.	3	5°	40–60	$\frac{1}{32}$–$2\frac{1}{2}$
	2	Rad.	6	5°	40–60	$\frac{1}{32}$–$2\frac{1}{2}$
Steel (low carbon)	3	Rad.	3	5°	40–60	2–$3\frac{1}{2}$
	2	Rad.	2	10°	40–60	2–$3\frac{1}{2}$
Cast iron	3	Rad.	3	Rad.	50–70	3–5
Bronze	3	Rad.	3	10°	150–250	10–15
Brass	3	Rad.	3	15°	300–700	12–20
Copper	1	5°	1	20°	500–700	10–20
	3	5°	3	20°	500–700	10–20
Aluminium	1	10°	1	25°	800–1,000	40–80
Monel	3	Rad.	3	5°	100–200	2–$3\frac{1}{2}$

Style 1	*Style* 2	*Style* 3
Regular straight metal saw tooth	Alternate square and bevelled metal saw tooth	Regular topped metal saw tooth

TABLE XV

SPEEDS AND FEEDS FOR FAST-RUNNING METAL SAWS

(*Circular—Medium and Mild Temper*)

Material to be Cut	*Saw Arbor above Work*		*Saw Arbor below Work*		*Rim Speed in Feet per Min.*	*Feed in Inches per Min.*
	Style Tooth	*Hook Angle*	*Style Tooth*	*Hook Angle*		
Bronze	2 3	Rad. Rad.	2 3	10° 10°	750– 3,000	20–30 20–30
Brass	1 3	Rad. Rad.	1 3	15° 15°	1,000– 6,000	50–60 50–60
Copper	1 2	5° 5°	1 2	20° 20°	750– 6,000	60–70 60–70
Aluminium ..	1	10°	1	25°	800–1,000	70–90
Zinc	1	5°	1	20°	800	70–90

Style 1	*Style* 2	*Style* 3
Regular straight metal saw tooth	Alternate square and bevelled metal saw tooth	Regular topped metal saw tooth

TABLE XVI

SPEEDS AND FEEDS FOR INSERTED TOOTH CIRCULAR METAL SAWS

Material	*Recommendations*	
	Rim Speed (ft./min.)	*Feed (sq. in./min.)*
Steel..	40	$2\frac{1}{2}$–10
Cast iron	40	5
Brass	500	80
Copper	750	60
Aluminium	1,200	90

Milling.—Speeds of milling cutters can be somewhat higher than the equivalent peripheral speeds for continuous cut, such as turning or drilling, as the teeth have time to cool between each successive cut.

The feed to be used with milling depends upon the speed of the cutter in revolutions per minute, the number of teeth in the cutter, and the feed per tooth. The feed per tooth is a very important function, as the whole cutting operation of a milling cutter depends upon this. Too fine a feed per tooth will cause over-heating and more teeth will slide over the work-piece than cut; too great a feed per tooth in the case of end mills can impart too high a load on the cutter and cause breakage.

A feed per tooth of approximately 0·002 in. is recommended for end mills in steel, 0·005 in. for aluminium, and a feed per tooth of 0·005 in. for slot cutters, facing cutters, etc., in steel is up to 0·020 in. per tooth in aluminium. Rake angles for milling cutters are somewhat less than those for continuous cut, and in special instances with carbide-tooth milling cutters cutting steel should be negative.

TABLE XVII

SURFACE SPEEDS FOR MILLING CUTTERS

Material to be Milled	*Carbon-steel Cutters*	*H.S.S. Cutters*	*Tungsten-carbide Cutters*
Mild steel	25	90	800
Alloy steel (40 tons tensile) ..	20	80	700
Alloy steel (50 tons tensile) ..	—	60	600
Alloy steel (60 tons tensile) ..	—	40	500
Alloy steel (over 60 tons tensile)	—	20–40	300–500
Cast iron	15–50	20–90	650
Brass (rolled)	80	120	1,000
Brass (cast)	100	160	1,000–1,500
Copper	100–120	170	1,000
Bronze	30–90	30–90	800–1,500
Aluminium	500–1,000	500–1,000	1,000–10,000
Silicon aluminium	450–1,000	450–1,000	1,000–10,000
Duralumin	400–900	400–1,000	1,000–10,000
Magnesium alloy	400–900	400–1,000	1,000–10,000
Zinc-base alloy..	300–700	300–850	700–2,000

Grinding.—The speed of a grinding wheel depends upon the diameter, in order to maintain a peripheral speed of approximately 5,000 ft. per min. depending upon the type of wheel used. The speed is seldom less than 4,500 ft. per min., and speeds up to 7,000 ft. per min. are employed. Small wheels usually wear quicker than large ones, owing to the fact that each particular grain is in contact with the work more often with a small wheel than with a large wheel.

Width and depth of cut depend upon the power available and the rigidity of the machine in question. The feed on the work-piece should be such that a surface feed of approximately 20–30 ft. per min. can be maintained in accordance with the type and quality of the work desired.

Table XVIII

Recommended Rake Angles for Milling Cutters

Material to be Cut	*H.S.S. Cutters*		*Tungsten Carbide-tipped Cutters*	
	Radial Rake (deg.)	*Axial Rake (deg.)*	*Radial Rake (deg.)*	*Axial Rake (deg.)*
Mild steel	+8	0–+5	−5	−10
Alloy steel (40 tons) ..	+8	0–+5	−7	−10
Alloy steel (50 tons) ..	+5	0–+5	−10	−10
Alloy steel (60 tons) ..	+5	0–+5	−10	−10
Alloy steel (over 60 tons)	+5	0–+5	−10	−10
Cast iron	+10	0–+10	+7	−10
Brass (rolled)	+10	0–+10	+8	+8
Brass (cast)	0–+2	0	0–+2	0
Aluminium alloy	+8–+12	0–+10	+10	+10
Duralumin	+8–+12	0–+10	+8	+10

Table XIX

Metal Removal Rates

Material	*Cu. in. per H.P. per Min.*	*Material*	*Cu. in. per H.P. per Min.*
Mild steel (35 tons tensile)..	0·75	Soft brass	2·3
Steel (45 tons tensile) ..	0·87	Hard brass	0·9
Steel (65 tons tensile) ..	0·87	Bronze	1·2
Steel (90 tons tensile) ..	0·87	Aluminium	3·0
Cast iron	0·9	Silicon alloy	2·7
Cast iron inoculated ..	1·0	Zinc-base alloy ..	3·5
Copper	2·0	Duralumin	2·7
Cupro-nickel..	1·0	Magnesium alloy ..	3·5

THE SPEED AND FEED CALCULATING GRAPH

To Obtain Speed of Cutter in R.P.M.—In Fig. 33 the vertical and horizontal axes represent feet per minute and diameter of cutter respectively. To obtain the revolutions per minute for a given surface speed and diameter of cutter, first look up the surface speed required on the vertical axis and run across the horizontal line until the intersection with the vertical line passes through the

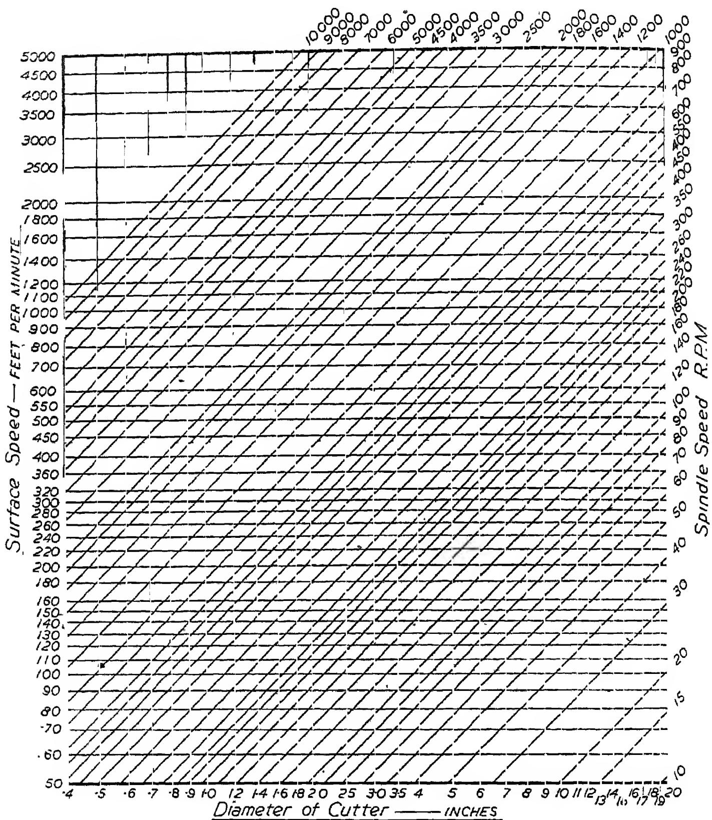


Fig. 33.—Graph correlating surface speed, diameter of cutter and spindle speed.

diameter of the cutter required. Pass along the nearest oblique line to this intersection in order to read the revolutions per minute upon the vertical axis to the right hand of the graph.

To Obtain Table Feed for Given Cutter Conditions.—In Fig. 34 the vertical and horizontal axes represent cutter speeds in revolutions per minute

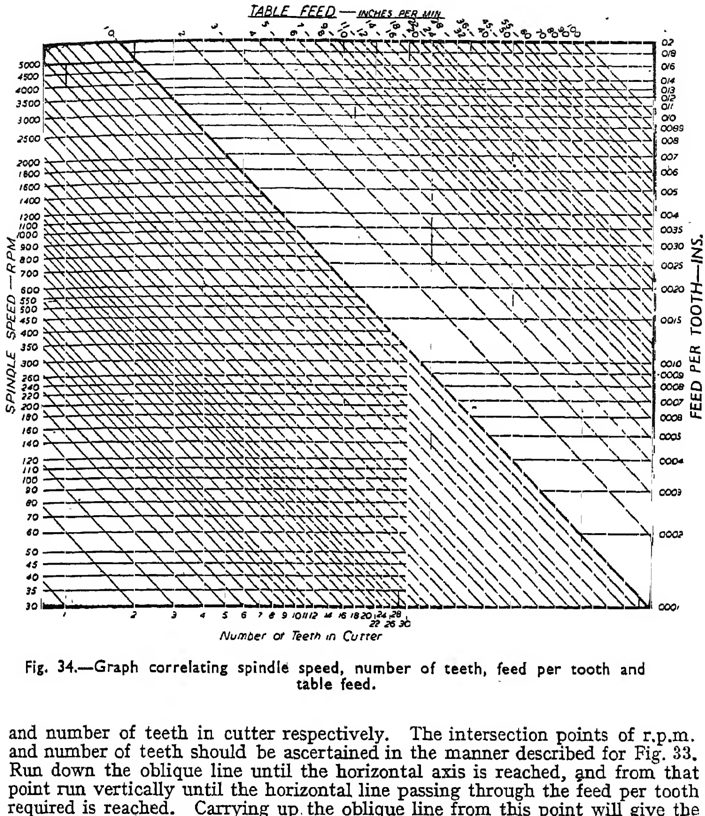


Fig. 34.—Graph correlating spindle speed, number of teeth, feed per tooth and table feed.

and number of teeth in cutter respectively. The intersection points of r.p.m. and number of teeth should be ascertained in the manner described for Fig. 33. Run down the oblique line until the horizontal axis is reached, and from that point run vertically until the horizontal line passing through the feed per tooth required is reached. Carrying up the oblique line from this point will give the table feed along the horizontal axis at the top of the graph.

To Find the Horse-power Required for Given Cut.—In Fig. 35 the vertical and horizontal axes represent width and depth of cut respectively. The intersection point of the width and depth required should be found, and the oblique line passing through that point should be followed to the base of the graph. Following the vertical line from this point until it intersects with the horizontal line passing through table feed will give an intersection point which indicates an oblique line which should be run along until it reaches one of the horizontal scales at the top of the graph corresponding to the particular materials being operated upon. This gives a very useful approximation to the horse-power required for a cutter well sharpened.

The horse-power so obtained is horse-power at the cutter, and does not include the horse-power required to overcome friction in the machine or to feed the table.

To Obtain Peripheral Speed of Cutter.—In Fig. 33 find the intersection point of spindle speeds in r.p.m. and cutter diameter in inches. The corresponding peripheral speeds in feet per minute can then be read off from the vertical scale at the left-hand side of the graph.

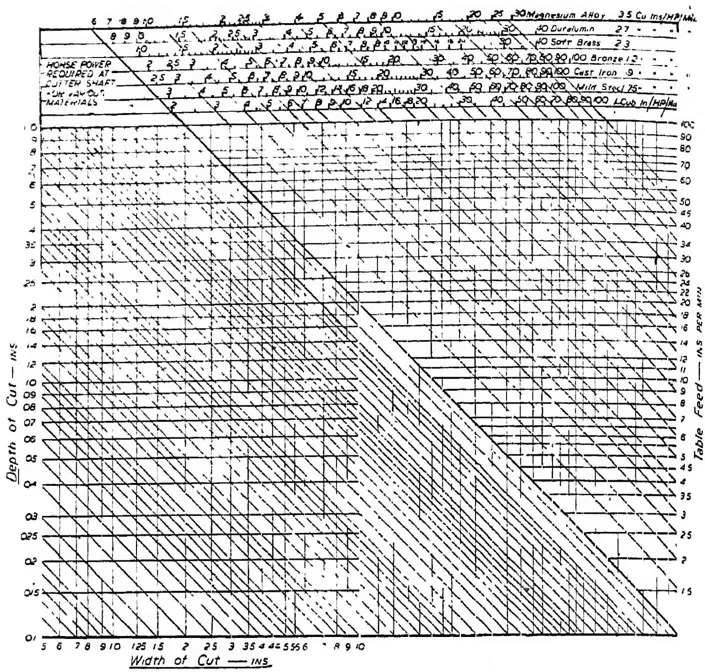


Fig. 35.—Graph correlating depth and width of cut, table feed and H.P. required.

Cutter Giving Peripheral Speed at Known Spindle Speed.—Find intersection point of peripheral speed required in feet per minute on vertical scale at left-hand side of the graph and r.p.m. of spindle on the oblique line. Reading this intersection point off the horizontal scale will give cutter diameter in inches.

To Find Table Feed for Given Cut with Given Horse-power.—In Fig. 35 find intersection point of depth and width of cut on vertical and horizontal scales respectively; follow the nearest oblique line to the intersection point to the base of the graph, and follow the vertical line thence until it intersects with the horse-power available read off on the appropriate material scale.

From this intersection point the table feed can be determined on the vertical to the right-hand side of the graph.

Depth of Cut Possible with Given Horse-power and Table Speed.—From the horse-power of the scale appropriate to the material being used, follow the oblique line until it intersects with the horizontal line representing the table feed. Follow this intersection point downwards to the base of the graph, and follow the oblique line from this point until it intersects with the vertical line from the width of cut. Following the nearest horizontal line to this intersection point, the depth of cut possible will be found on the vertical scale to the left-hand side of the graph.

Number of Teeth in Cutter for Given Spindle Speed and Table Feed.—Starting at table-feed scale at the top of the page, follow the oblique line until it intersects with the desired feed per tooth. At this intersection point follow the

nearest vertical line to the bottom of the graph, and then follow the oblique line until it intersects with the spindle speeds. The nearest vertical line to this intersection point gives the number of teeth that the cutter should have for resubmission.

Feed per Tooth.—Find the intersection point of spindle speed and number of teeth in cutter. Follow the nearest oblique line to this intersection point to the base of the graph, and follow the vertical line at this point until it intersects the oblique line corresponding to table feed. The horizontal line passing nearest to this point will indicate the feed per tooth.

WEIGHTS OF WOODS

The weights of dry woods are as follow:

Substance	*Weight lb. per cub. ft.*	*Substance*	*Weight lb. per cub. ft.*
Alder	33	Hickory	50
Almond	43	Holly	38
Ash, American	40	Hornbeam	45
Ash, European	43	Ironwood	75
Ash, Mountain	43	Jarrah	57
Balsa	7/8	Juniper	37
Bamboo	25	Lancewood	57
Beech, Common	46	Larch	38
Beech, Australian	33	Lignum-vitae	83
Birch, American	42	Lime or Linden	32
Birch, English	45	Logwood	57
Boxwood, Cape	52	Mahogany, East Indian	43
Boxwood, West Indian	49	Mahogany, Cuban	47
Boxwood, Common	76	Mahogany, Australian	69
Cedar, Cuban	28	Mahogany, Spanish	48
Cedar, Virginian	33	Maple, Bird's-eye	36
Cedar, Indian	28	Maple, Hard	42
Cherry, American	36	Maple, Soft	38
Cherry, English	38	Oak, African	59
Chestnut, Sweet	40	Oak, American	45
Chestnut, Horse	35	Oak, Danzig	52
Cocus	69	Oak, English	46
Cogwood	67	Pine, Pitch	44
Cork	16	Pine, Red	34
Cottonwood, American	34	Pine, White	27
Cypress	30	Pine, Yellow	33
Dogwood	49	Plane	35
Ebony	73	Poplar	26
Elder	40	Rosewood	55
Elm, American	44	Satinwood	58
Elm, Common	42	Spruce	30
Fir, Danzig	38	Sycamore	40
Fir, Riga	36	Teak	50
Fir, Silver	30	Walnut	41
Fir, Spruce	30	Whitewood	33
Hackmatack	39	Willow	33
Hazel	39	Yew	52

Timber is usually felled in the winter, when the sap is at its lowest ebb. It then has a moisture content of 12 per cent. approx., as stipulated by B.S.S. 373/1929.

This moisture content is determined by weighing a certain amount of a given sample; drying in an oven until it ceases to lose weight and then weighing again. Its calculated moisture percentage is as follows:

$$\text{Moisture content \%} = \frac{(\text{Original weight} - \text{dry weight})}{\text{Dry weight}} \times 100.$$

CALCULATING BENDING ALLOWANCES

In order to find the amount of metal contained in a bend, the usual formula is:

$$2\pi(r + \tfrac{2}{5}G) \times \frac{\text{External Angle}}{360°}$$

For a 90° bend, 9 S.W.G., $2\tfrac{1}{2}$G radius,

$$\text{B.A.} = 2\pi(r + \tfrac{2}{5}G) \times \frac{\text{Ext. Angle}}{360}$$

$$= 2\pi(2\tfrac{1}{2}G + \tfrac{2}{5}G)\ \frac{90}{360}$$

$$= \tfrac{1}{2}\pi \times 2{\cdot}9G$$

$$= 1{\cdot}571 \times 2{\cdot}9G$$

$$\text{B.A.} = 4{\cdot}56G.$$

$$\text{Similarly B.A. for } 120° = 4{\cdot}56G \times \frac{120}{90}$$

$$\text{B.A. for } 45° = 4{\cdot}56G \times \frac{45}{90}$$

and so on. The table of simple multipliers covers 6–26 S.W.G. 1G, to 6–26 S.W.G. 3G, 90° bends in steps of $\tfrac{1}{2}$G radii.

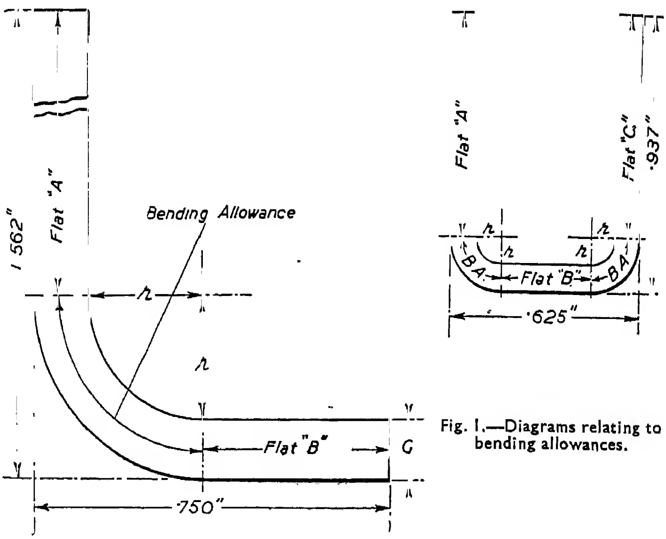


Fig. 1.—Diagrams relating to bending allowances.

The "$\tfrac{2}{5}$G" formula is generally taken as the basis for tables of gauges up to 12, and the "$\tfrac{1}{2}$G" formula as the basis for gauges of 13 and above. It cannot be possible that the normal zone suddenly slips from $\tfrac{2}{5}$ths to $\tfrac{1}{2}$-way across the material by making it ·012 in. thinner; so between these gauges a rather large error creeps in which makes it necessary to make "private" allowances on the figures taken from the tables.

In all of the following tables this necessity has been avoided, as the tables are calculated from formulæ based as follows:

6– 9 S.W.G.	..	" . . . $(r + \frac{2}{5}G)$ "
10–13 S.W.G.	..	" . . . $(r + \frac{9}{20}G)$ "
14–26 S.W.G.	..	" . . . $(r + \frac{1}{2}G)$ "

thus blending the error over a number of gauges and making it as near as possible negligible.

The application of the tables is in no way different from the generally accepted method:

(1) Draw a rough enlarged diagram of the piece (see Fig. 1).

(2) Separate the flats from the bends by drawing a pair of radii, and dimension your drawing.

The quantity in the table now represents the part of the figure marked bending allowance.

BENDING ALLOWANCE.

Flat "A" = 1·562 in. − $(r + G)$
Flat "B" = ·750 in. − $(r + G)$
Total plate required = *"A" + "B" + Bending Allowance.*

Similarly in Fig 2.
Flat "A" = ·937 in. − $(r + G)$
Flat "C" = ·937 in. − $(r + G)$
Flat "B" = ·625 in. − $2(r + G)$.
Total plate = 2 *"A" + "B" + 2 Bending Allowance.*

TABLE OF SIMPLE MULTIPLIERS

S.W.G.	*In.*	*Between 90° Bending Allowance =*			*Inside Radius =*
6	·192				
7	·176	6 and 9 S.W.G.	..	G × 2·20	
8	·160	10 and 13 S.W.G.	..	G × 2·28	1 G
9	·144	14 and 26 S.W.G.	..	G × 2·35	
10	·128				
11	·116	6 and 9 S.W.G.	..	G × 2·98	
12	·104	10 and 13 S.W.G.	..	G × 3·06	1½ G
13	·092	14 and 26 S.W.G.	..	G × 3·14	
14	·080				
15	·072	6 and 9 S.W.G.	..	G × 3·77	
16	·064	10 and 13 S.W.G.	..	G × 3·85	2 G
17	·056	14 and 26 S.W.G.	..	G × 3·93	
18	·048				
19	·040	6 and 9 S.W.G.	..	G × 4·56	
20	·036	10 and 13 S.W.G.	..	G × 4·63	2½ G
21	·032	14 and 26 S.W.G.	..	G × 4·71	
22	·028				
23	·024	6 and 9 S.W.G.	..	G × 5·34	
24	·022	10 and 13 S.W.G.	..	G × 5·42	3 G
25	·020	14 and 26 S.W.G.	..	G × 5·50	
26	·018				

Bending allowances for other angles are in direct proportion. Thus:

B.A. for 16 G, 90°, 2G radius = ·251 in.

B.A. for 16 G, 45°, 2G radius = $\frac{\cdot 251}{2}$ = ·125 in.

B.A. for 16 G, 120°, 2G radius = $\frac{\cdot 251 \times 4}{3}$ = ·335 in.

	1G							1¼G							
S.W.G.	10°	20°	30°	60°	90°	120°	150°	S.W.G.	10°	20°	30°	60°	90°	120°	150°
6	·047	·094	·141	·281	·422	·563	·703	6	·064	·127	·191	·381	·572	·763	·953
7	·043	·086	·129	·258	·387	·516	·645	7	·058	·116	·175	·349	·524	·699	·873
8	·039	·078	·117	·235	·352	·469	·587	8	·053	·106	·159	·318	·477	·636	·795
9	·035	·070	·106	·211	·317	·423	·528	9	·048	·096	·143	·286	·429	·572	·715
10	·032	·065	·097	·195	·292	·389	·487	10	·043	·087	·130	·261	·391	·521	·652
11	·029	·059	·088	·176	·264	·352	·440	11	·039	·079	·118	·237	·355	·473	·592
12	·026	·053	·079	·158	·237	·316	·395	12	·035	·071	·106	·212	·318	·424	·530
13	·023	·046	·070	·139	·209	·279	·348	13	·031	·063	·094	·188	·282	·376	·470
14	·021	·042	·063	·125	·188	·251	·313	14	·028	·056	·084	·167	·251	·335	·418
15	·019	·037	·056	·113	·169	·225	·282	15	·025	·050	·075	·151	·226	·301	·377
16	·017	·033	·050	·100	·150	·200	·250	16	·022	·045	·067	·134	·201	·268	·335
17	·015	·029	·044	·088	·132	·176	·220	17	·020	·039	·059	·117	·176	·235	·293
18	·013	·025	·038	·075	·113	·151	·188	18	·017	·033	·050	·101	·151	·201	·252
19	·010	·021	·031	·063	·094	·125	·157	19	·014	·028	·042	·084	·126	·168	·210
20	·009	·019	·028	·056	·084	·112	·140	20	·013	·025	·038	·075	·113	·151	·188
21	·008	·017	·025	·050	·075	·100	·125	21	·011	·022	·033	·067	·100	·134	·167
22	·007	·015	·022	·043	·065	·087	·108	22	·010	·019	·029	·059	·088	·117	·147
23	·006	·013	·019	·037	·056	·075	·093	23	·008	·017	·025	·050	·075	·100	·125
24	·006	·012	·017	·035	·052	·069	·087	24	·008	·015	·023	·046	·069	·092	·115
25	·005	·010	·016	·031	·047	·063	·078	25	·007	·014	·021	·042	·063	·084	·105
26	·005	·009	·014	·028	·042	·056	·070	26	·006	·013	·019	·037	·056	·075	·093

To find B. Allowance for 1G, 12 S.W.G., 47°

$40° = 30° + 10° \quad = ·105$

$7° = \frac{1}{10} \times 70° \quad = ·018$

$47° \quad = ·122''$

To find B. Allowance for 1G, 16 S.W.G., 64°

$60° \quad = ·100$

$4° = \frac{1}{10} \times 40° \quad = ·007$

$64° \quad = ·107''$

To find B. Allowance for 1½G, 20 S.W.G., 125°

$120° \quad = ·151$

$5° = \frac{1}{2} \times 10° = ·006$

$125° \quad = ·157''$

BENDING ALLOWANCE FOR $r = 2G$

S.W.G.	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°
6	·080	·161	·241	·322	·402	·483	·563	·643	·724	·804	·885	·965	1·046	1·126	1·207	1·287	1·367
7	·074	·147	·221	·295	·368	·442	·516	·589	·663	·737	·810	·884	·958	1·031	1·105	1·179	1·252
8	·067	·134	·201	·268	·335	·402	·469	·536	·603	·670	·737	·804	·871	·938	1·005	1·072	1·139
9	·061	·120	·181	·242	·301	·362	·422	·482	·543	·604	·663	·724	·785	·844	·905	·965	1·025
10	·055	·109	·164	·219	·273	·329	·383	·438	·493	·548	·602	·657	·712	·866	·822	·876	·931
11	·049	·099	·150	·199	·249	·298	·347	·397	·446	·495	·545	·596	·646	·695	·744	·793	·843
12	·044	·089	·135	·179	·223	·267	·311	·356	·400	·444	·489	·535	·579	·623	·667	·711	·756
13	·039	·079	·119	·158	·197	·236	·275	·315	·354	·393	·433	·473	·512	·551	·590	·629	·669
14	·035	·070	·105	·140	·175	·209	·244	·279	·314	·349	·384	·419	·454	·489	·523	·558	·593
15	·032	·063	·095	·126	·158	·189	·220	·252	·283	·315	·346	·378	·409	·441	·472	·503	·535
16	·028	·056	·084	·112	·140	·168	·195	·224	·251	·279	·307	·335	·363	·391	·419	·446	·475
17	·025	·049	·074	·098	·123	·147	·171	·196	·220	·245	·269	·294	·318	·343	·367	·391	·416
18	·021	·042	·063	·084	·105	·126	·147	·168	·189	·210	·231	·252	·273	·294	·315	·336	·357
19	·018	·035	·053	·070	·087	·104	·122	·140	·157	·175	·192	·210	·227	·244	·261	·279	·297
20	·016	·031	·047	·063	·079	·094	·110	·126	·141	·157	·172	·188	·204	·220	·235	·251	·267
21	·014	·028	·042	·056	·070	·083	·098	·112	·126	·140	·154	·168	·182	·196	·209	·224	·238
22	·012	·024	·037	·049	·061	·073	·086	·098	·110	·122	·134	·147	·159	·171	·183	·196	·208
23	·011	·021	·032	·042	·052	·063	·073	·084	·094	·105	·115	·126	·136	·146	·157	·167	·178
24	·010	·019	·029	·038	·048	·058	·067	·077	·086	·096	·105	·115	·124	·134	·144	·153	·163
25	·009	·017	·026	·035	·044	·053	·061	·070	·078	·087	·095	·104	·113	·122	·131	·139	·148
26	·008	·016	·024	·032	·040	·048	·055	·063	·070	·078	·086	·094	·102	·110	·117	·125	·133

	2½G							3G						
S.W.G.	10°	20°	30°	60°	90°	120°	150°	S.W.G.	10°	20°	30°	60°	90°	120°	150°
6	·097	·195	·292	·584	·876	1·168	1·460	6	·114	·228	·342	·683	1·025	1·367	1·708
7	·089	·178	·268	·535	·803	1·071	1·338	7	·104	·209	·313	·627	·940	1·253	1·567
8	·081	·162	·243	·487	·730	·973	1·217	8	·095	·190	·285	·569	·854	1·139	1·423
9	·073	·146	·219	·438	·657	·876	1·095	9	·085	·171	·256	·513	·769	1·025	1·282
10	·066	·132	·198	·395	·593	·791	·988	10	·077	·153	·231	·462	·693	·924	1·155
11	·060	·120	·179	·359	·538	·717	·897	11	·070	·140	·210	·419	·629	·839	1·048
12	·054	·107	·161	·322	·483	·644	·805	12	·063	·125	·188	·376	·564	·752	·940
13	·047	·095	·142	·285	·427	·569	·712	13	·055	·111	·166	·333	·499	·665	·832
14	·042	·084	·126	·251	·377	·503	·628	14	·049	·098	·147	·293	·440	·587	·733
15	·038	·075	·113	·226	·339	·452	·565	15	·044	·088	·132	·264	·396	·528	·660
16	·033	·067	·100	·201	·301	·401	·502	16	·039	·078	·117	·235	·352	·469	·587
17	·029	·059	·088	·176	·264	·352	·440	17	·034	·068	·103	·205	·308	·411	·513
18	·025	·050	·075	·151	·226	·301	·377	18	·029	·059	·088	·176	·264	·352	·440
19	·021	·042	·063	·125	·188	·251	·313	19	·024	·049	·073	·147	·220	·293	·367
20	·019	·038	·057	·113	·169	·226	·282	20	·022	·044	·066	·132	·198	·264	·330
21	·017	·033	·050	·100	·150	·200	·250	21	·020	·039	·059	·117	·176	·235	·293
22	·015	·029	·044	·088	·132	·176	·220	22	·017	·034	·051	·103	·154	·205	·257
23	·013	·025	·038	·075	·113	·151	·188	23	·015	·029	·044	·088	·132	·176	·220
24	·012	·023	·035	·069	·104	·139	·173	24	·013	·027	·040	·081	·121	·161	·202
25	·010	·021	·031	·063	·094	·125	·157	25	·012	·024	·037	·073	·110	·147	·183
26	·009	·019	·028	·056	·084	·112	·140	26	·011	·022	·033	·066	·099	·132	·165

To find B. Allowance for 2½G., 14 S.W.G., 56°

50° = 30° + 20° = ·210

$6° = \frac{1}{10} \times 60°$ = ·025

56° = ·235″

To find B. Allowance for 3G, 7 S.W.G., 141°

140° = 120° + 20° = 1·462

$1° = \frac{1}{10} \times 10°$ = ·010

141° = 1·472″

TUBE AND SECTION BENDING

The following tables have been compiled to enable bending-machine operators to see at a glance the type of Former to use for tubes and sections of various radii; also the most suitable machine to use.

Provided the machine is used correctly, satisfactory results should be obtained, but it must be remembered that as some of the tables include steel, brass, and copper tubes in one group, some variations may occur; as for instance, the bend made in copper would, in many cases, be superior to a similar bend in steel.

The number or size of the benders mentioned in these tables denote the following Kennedy machines:

1149 = No. 1149 Flat Strip Bender.
1 = No. 1 Universal Bender.
2 = No. 2 Universal Bender.
2G = No. 2 Geared Universal Bender.
2AU = No. 2A Universal Bender.
3A = No. 3A Universal Bender.
1212 = No. 1212 Bar Bender.
1213 = No. 1213 Bar Bender.
2A = No. 2A Bar Bender.
4 = No. 4 Bar Bender.

TABLES SHOWING VARIOUS RADII TO WHICH M.S. STRIP CAN BE BENT ON EDGE, WITH SUITABLE TYPES OF BENDING MACHINES IN EACH CASE.

Radii to which ½-in. wide M.S. Strip may be bent *on edge.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*													
		1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½
in.															
$\frac{1}{16}$	0·106	←		1		→	←				2		→		
⅛	0·2125	←		1			→								
						←					2		→		
$\frac{3}{16}$	0·32	←		1			→								
						←					2		→		
¼	0·43	←			1			→							
							←				2				→
$\frac{5}{16}$	0·53	←			1			→							
							←				2				→
⅜	0·64	←			1			→							
							←				2				→

Radii to which ⅝-in. wide M.S. Strip may be bent *on edge.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*													
		1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½
in.															
$\frac{1}{16}$	0·133	←		1	→	←					2			→	
⅛	0·266	←		1	→										
				←							2			→	
$\frac{3}{16}$	0·40	←		1	→	←					2			→	
[illegible]	0·53	←		1	→	←					2				→
[illegible]	0·80	←		1		→									
						←					2				→
½	1·06	←		1		→	←				2				→

Radii to which $\frac{3}{4}$-**in.** wide M.S. Strip may be bent *on edge*.

Thickness of Strip	*Weight in lb. per ft.*	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5½	6	6½	7	7½	8
in.																							
$\frac{1}{16}$	0·159		←	1	→		←			2			→										
$\frac{1}{8}$	0·318	←		1		→																	
						←				2			→										
$\frac{3}{16}$	0·48	←		1		→	←			2			→										
$\frac{1}{4}$	0·64		←	1		→	←			2			→										
$\frac{5}{16}$	0·80		←	1		→	←			2			→										
$\frac{3}{8}$	0·95						←			2			→										
$\frac{1}{2}$	1·28						←			2			→										
									←							2 AU							→
$\frac{5}{8}$	1·59						←			2			→										
									←							2 AU							→

Radii to which $\frac{7}{8}$-**in.** wide M.S. Strip may be bent *on edge*.

Thickness of Strip	*Weight in lb. per ft.*	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5½	6	6½	7	7½	8	8½	9
in.																									
$\frac{1}{16}$	0·186		←	1	→		←		2				→												
$\frac{1}{8}$	0·3719	←		1	→	←			2				→												
$\frac{3}{16}$	0·56	←		1	→	←			2				→												
$\frac{1}{4}$	0·75		←		1	→	←			2			→												
$\frac{3}{8}$	1·12						←			2			→												
$\frac{1}{2}$	1·49						←			2			→												
									←								2 AU						→		
$\frac{5}{8}$	1·86						←			2			→												
									←								2 AU						→		

Radii to which **1-in.** wide M.S. Strip may be bent *on edge*.

Thickness of Strip	*Weight in lb. per ft.*	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5½	6	6½	7	7½	8	8½	9
in.																									
$\frac{1}{16}$	0·2125	←	1	→		←			2				→												
$\frac{1}{8}$	0·425	←		1	→	←			2				→												
$\frac{3}{16}$	0·64	←		1	→	←			2				→												
$\frac{1}{4}$	0·85					←			2				→												
$\frac{5}{16}$	1·06						←		2				→												
$\frac{3}{8}$	1·28						←		2				→												
[illegible]	1·70								←						2 AU								→		
[illegible]	2·13								←						2 AU								→		
[illegible]	2·55								←						2 AU								→		

Radii to which $1\frac{1}{4}$-in. wide M.S. Strip may be bent *on edge*.

Thickness of Strip (in.)	Weight in lb. per ft.	Radius in Inches (from)	Radius in Inches (to)	
$\frac{1}{8}$	0·531	$2\frac{1}{4}$	4	2
$\frac{3}{16}$	0·80	$2\frac{1}{4}$	4	2
$\frac{1}{4}$	1·06	$2\frac{1}{4}$	4	2
$\frac{3}{8}$	1·59	3	$6\frac{1}{2}$	2 AU
		$3\frac{3}{4}$	7	3A
$\frac{1}{2}$	2·13	3	$6\frac{1}{2}$	2 AU
		$3\frac{3}{4}$	7	3A
$\frac{5}{8}$	2·66	3	$6\frac{1}{2}$	2 AU
		$3\frac{3}{4}$	7	3A
$\frac{3}{4}$	3·19	$3\frac{3}{4}$	7	3A

Radii to which $1\frac{3}{8}$-in. wide M.S. Strip may be bent *on edge*.

Thickness of Strip (in.)	Weight in lb. per ft.	Radius in Inches (from)	Radius in Inches (to)	
$\frac{1}{4}$	1·17	$2\frac{1}{4}$	$3\frac{3}{4}$	2 G
		$3\frac{3}{4}$	$8\frac{1}{2}$	3A
		$3\frac{1}{4}$	$7\frac{1}{2}$	2 AU
$\frac{3}{8}$	1·75	$3\frac{1}{4}$	$7\frac{1}{2}$	2 AU
		$3\frac{3}{4}$	$8\frac{1}{2}$	3A
$\frac{1}{2}$	2·34	$3\frac{1}{4}$	$7\frac{1}{2}$	2 AU
		$3\frac{3}{4}$	$8\frac{1}{2}$	3A

Radii to which $1\frac{1}{2}$-in. wide M.S. Strip may be bent *on edge*.

Thickness of Strip (in.)	Weight in lb. per ft.	Radius in Inches (from)	Radius in Inches (to)	
$\frac{1}{8}$	0·64	$2\frac{3}{4}$	$3\frac{1}{2}$	2 G
		$3\frac{1}{4}$	$7\frac{1}{2}$	2 AU
$\frac{1}{4}$	1·28	$2\frac{3}{4}$	$3\frac{1}{2}$	2 G
		$3\frac{1}{4}$	$7\frac{1}{2}$	2 AU
$\frac{3}{8}$	1·91	$3\frac{3}{4}$	$8\frac{1}{2}$	3 A
		$3\frac{1}{2}$	$7\frac{1}{2}$	2 AU
$\frac{1}{2}$	2·55	$3\frac{3}{4}$	$8\frac{1}{2}$	3 A
$\frac{5}{8}$	3·19	$3\frac{3}{4}$	$8\frac{1}{2}$	3 A
$\frac{3}{4}$	3·83	$3\frac{3}{4}$	$8\frac{1}{2}$	3 A
$\frac{7}{8}$	4·46	$3\frac{3}{4}$	$8\frac{1}{2}$	3 A
1	5·1	$3\frac{3}{4}$	$8\frac{1}{2}$	3 A

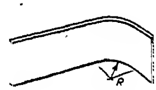
Radii to which **2-in.** wide M.S. Strip may be bent *on edge.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*: $1\frac{1}{4}$ $1\frac{1}{2}$ $1\frac{3}{4}$ 2 $2\frac{1}{4}$ $2\frac{1}{2}$ $2\frac{3}{4}$ 3 $3\frac{1}{4}$ $3\frac{1}{2}$ $3\frac{3}{4}$ 4 $4\frac{1}{4}$ $4\frac{1}{2}$ $4\frac{3}{4}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 $7\frac{1}{2}$ 8 $8\frac{1}{2}$ 9
in.		
$\frac{1}{8}$	0·85	← - - - 2 AU - - - →
		← - - - - - - - - 3A - - →
$\frac{3}{16}$	1·28	← - - - - - 2 AU - - - →
		← - - - - - - 3A - - - - →
$\frac{1}{4}$	1·70	← - - - - - - - 2 AU - - - →
		← - - - - - - 3A - - - - →
$\frac{5}{16}$	2·13	← - - - - - - 3A - - - - →
$\frac{1}{2}$	2·55	← - - - - - - 3A - - - - →

The reader is referred to the section entitled *Bending Allowances* on page 652 for calculations relating to bending, and to the table of simple multipliers on page 653.

Tables showing Various Radii to which M.S. Flats can be Bent with Suitable Types of Bending Machines in each Case

Radii to which **½-in.** wide Flats may be bent *on the flat.*



Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*: $\frac{1}{64}$ $\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{3}{8}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9
20 g.	0·067	←— 1149 - - → ← - - 1 21 2 - - →
		← - - - - 1 21 3 - - - - →
16 g.	0·106	← - - 1149 - - → ← - - 12 12 - - →
		← - - - - 1 21 3 - - - - →
$\frac{1}{8}$ in.	0·213	← - 114 9 → ← - - 12 12 - - →
		← - - - - 1 21 3 - - - - →
$\frac{3}{16}$ in.	0·32	← - 114 9 → ← - - 12 12 - - →
		← - - - - 1 21 3 - - - - →
$\frac{1}{4}$ in.	0·43	← 11 49 → ← - - 12 12 - - →
		← - - - - 12 13 - - - →
$\frac{3}{8}$ in.	0·64	← 11 49 → ← - - 12 12 - - →
		← - - - - 12 13 - - - →

Radii to which $\frac{5}{8}$-in. wide Flats may be bent *on the flat.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*
		$\frac{1}{64}$ $\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{3}{8}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9
20 g.	0·083	← - - 1149 - - → ← - - -1 21 2 - - - →
		← - - - - -1 21 3 - - - - - →
16 g.	0·133	← - - 1149 - - → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
$\frac{1}{8}$ in.	0·266	← -114 9 → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
$\frac{3}{16}$ in.	0·4	← -114 9 → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
$\frac{1}{4}$ in.	0·53	←11 49→ ← - - 12 12 - - →
		← - - - - 12 13 - - - - →
$\frac{3}{8}$ in.	0·80	←11 49→ ← - - 12 12 - - →
		← - - - - 12 13 - - - - →
$\frac{1}{2}$ in.	1·06	← - - 12 12 - - →
		← - - - - 12 13 - - - - →

Radii to which $\frac{3}{4}$-in. wide Flats may be bent *on the flat.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*
		$\frac{1}{64}$ $\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{3}{8}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9
20 g.	0·1	← - - -1 149 - - - → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
16 g.	0·159	← - - -1 149 - - - → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
$\frac{1}{8}$ in.	0·319	← -114 9 → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
$\frac{3}{16}$ in.	0·48	← -114 9 → ← - - 12 12 - - →
		← - - - - -1 21 3 - - - - - →
$\frac{1}{4}$ in.	0·64	←11 49→ ← -1 21 2 - →
		← - - - - 12 13 - - - - →
$\frac{5}{16}$ in.	0·80	←11 49→ ← -1 21 2 - →
		← - - - - 12 13 - - - - →
$\frac{3}{8}$ in.	0·95	← -1 21 2 - →
		← - - - - 12 13 - - - - →

Radii to which $\frac{7}{8}$-**in.** wide Flats may be bent *on the flat.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*: $\frac{1}{64}$ $\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{3}{8}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9
16 g.	0·186	← - - - 1149 - - - → ← - - 1212 - - → ← - - - - - 1213 - - - - - →
$\frac{1}{8}$ in.	0·372	← - 1149 - → ← - - 1212 - - → ← - - - - - 1213 - - - - - →
$\frac{3}{16}$ in.	0·56	← 1149 → ← - 1212 - → ← - - - - 1213 - - - - →
$\frac{1}{4}$ in.	0·75	← 1149 → ← - 1212 - → ← - - - 1213 - - - →
$\frac{3}{8}$ in.	1·12	1149 ← - 1212 - → ← - - 1213 - - →
$\frac{1}{2}$ in.	1·49	1149 ← - - - - - - - - - - 2 A - - - - - - - - - - → ← - - - 1213 - - - →
$\frac{5}{8}$ in.	1·86	← - - - 1213 - - - → ← - - - - - - - - - - 2 A - - - - - - - - - - →

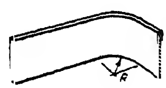
Radii to which **1-in.** wide Flats may be bent *on the flat.*

Thickness of Strip in.	*Weight in lb. per ft.*	*Radius in Inches*: $\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10
$\frac{1}{16}$	0·213	← - - 1149 - - → ← - - 1212 - - → ← - - - - 1213 - - - - →
$\frac{1}{8}$	0·425	← - - 1149 - - → ← - - 1212 - - → ← - - - - 1213 - - - - →
$\frac{3}{16}$	0·64	← - - 1149 - - → ← — 1212 — → ← - - - - 1213 - - - - →
$\frac{1}{4}$	0·85	← - 1149 → ← - - 1212 - - → ← - - - - 1213 - - - - →
$\frac{5}{16}$	1·06	← 1149 → ← - - 1212 - - → ← - - - - 1213 - - - - →
$\frac{3}{8}$	1·28	1149 ← - - 1212 - - → ← - - - - 1213 - - - - →
$\frac{1}{2}$	1·7	1149 ← - - - - 1213 - - - - → ← - - - - - - - - - 2 A - - - - - - - - - →
$\frac{5}{8}$	2·13	← - - - - 1213 - - - - → ← - - - - - - - - - 2 A - - - - - - - - - →
$\frac{3}{4}$	2·55	← - - - - 1213 - - - - → ← - - - - - - - - - 2 A - - - - - - - - - →

Radii to which $1\frac{1}{8}$-**in.** wide Flats may be bent *on the flat.*

Thick-ness of Strip	*Weight in lb. per ft.*	*Radius in Inches* ($\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10)
in.		
$\frac{1}{16}$	0·24	←-- 1149 --→←----- 12 13 -----→
		←-- 12 12 --→
$\frac{1}{8}$	0·48	←-- 1149 --→←----- 12 13 -----→
		←-- 12 12 --→
$\frac{3}{16}$	0·72	←- 1149 --→←----- 12 13 -----→
		←-- 12 12 --→
$\frac{1}{4}$	0·96	←11 49→←----- 12 13 -----→
		←-- 12 12 --→
$\frac{1}{2}$	1·91	1149←----- 12 13 -----→
		←------------- 2 A ------------→
$\frac{5}{8}$	2·4	←------------- 2 A ------------→

Radii to which $1\frac{1}{4}$-**in.** wide Flats may be bent *on the flat.*



Thick-ness of Strip	*Weight in lb. per ft.*	*Radius in Inches* ($\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10)
in.		
$\frac{1}{16}$	0·266	←-- 1149 --→ ←----- 12 13 -----→
$\frac{1}{8}$	0·53	←-- 1149 --→ ←----- 12 13 -----→
$\frac{3}{16}$	0·80	←-- 1149 --→ ←--- 2 ---→
$\frac{1}{4}$	1·06	←- 1149 --→ ←--- 2 ---→
$\frac{5}{16}$	1·33	←11 49→ ←--- 2 ---→
$\frac{3}{8}$	1·59	←- 2 G ---→
		←------------ 2 A -------------→
$\frac{1}{2}$	2·13	←------------ 2 A -------------→
		← - 2 G →
$\frac{5}{8}$	2·66	←------------ 2 A -----------→
$\frac{3}{4}$	3·19	←------------ 2 A -----------→
$\frac{7}{8}$	3·72	←------------ 2 A -----------→
1	4·25	←------------ 2 A -----------→
		←------------- 4 -------------→

Radii to which $1\frac{3}{8}$-in. wide Flats may be bent *on the flat*.

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*
		$\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10
in.		
$\frac{1}{4}$	1·17	←1 14 9→ ←- - - - - - - - - - - - - -4- - - - - - - - - - - - - - -→
		←- - - - - - - - - - - - - 2A - - - - - - - - - - - - -→
		← - - 2G - - →
$\frac{3}{8}$	1·75	←- - - - - - - - - - - - - -4- - - - - - - - - - - - - - -→
		←- - - - - - - - - - - - - 2A - - - - - - - - - - - - -→
		← - - 2G - - →
$\frac{1}{2}$	2·34	←- - - - - - - - - - - - - -4- - - - - - - - - - - - - - -→
		←- - - - - - - - - - - - - 2A - - - - - - - - - - - - -→
		← - - 2G →

SCREW THREADS FOR WATER, GAS, AND STEAM PIPES
British Standard Pipe and Whitworth Threads

Nominal Bore of Tube	*Approx. Outside Diameter of Black Tube*	*Diameter at Top of Thread*		*Diameter at Bottom of Thread*		*No. of Threads per In.*
		B.S.P.	*Whitworth*	*B.S.P.*	*Whitworth*	
in.	*in.*	*in.*	*in.*	*in.*	*in.*	
$\frac{1}{8}$	$\frac{13}{32}$	0·383	0·3825	0·337	0·3367	28
$\frac{1}{4}$	$\frac{17}{32}$	0·518	0·518	0·451	0·4506	19
$\frac{3}{8}$	$\frac{11}{16}$	0·656	0·6563	0·589	0·5889	19
$\frac{1}{2}$	$\frac{27}{32}$	0·825	0·8257	0·734	0·7342	14
$\frac{5}{8}$	$\frac{15}{16}$	0·902	0·9022	0·811	0·8107	14
$\frac{3}{4}$	$1\frac{1}{16}$	1·041	1·041	0·950	0·9495	14
$\frac{7}{8}$	$1\frac{7}{32}$	1·189	1·189	1·098	1·0975	14
1	$1\frac{11}{32}$	1·309	1·309	1·193	1·1925	11
$1\frac{1}{4}$	$1\frac{11}{16}$	1·650	1·650	1·534	1·5335	11
$1\frac{1}{2}$	$1\frac{29}{32}$	1·882	1·882	1·766	1·766	11
$1\frac{3}{4}$	$2\frac{5}{32}$	2·116	2·047	2·000	1·9305	11
2	$2\frac{3}{8}$	2·347	2·347	2·231	2·2305	11
$2\frac{1}{4}$	$2\frac{5}{8}$	2·587	2·587	2·471	2·471	11
$2\frac{1}{2}$	3	2·960	3·001	2·844	2·8848	11
$2\frac{3}{4}$	$3\frac{1}{4}$	3·210	3·247	3·094	3·1305	11
3	$3\frac{1}{2}$	3·460	3·485	3·344	3·3685	11
$3\frac{1}{4}$	$3\frac{3}{4}$	3·700	3·698	3·584	3·582	11
$3\frac{1}{2}$	4	3·950	3·912	3·834	3·7955	11
$3\frac{3}{4}$	$4\frac{1}{4}$	4·200	4·125	4·084	4·009	11
4	$4\frac{1}{2}$	4·450	4·339	4·334	4·2225	11
$4\frac{1}{2}$	5	4·950	—	4·834	—	11
5	$5\frac{1}{2}$	5·450	—	5·334	—	11
$5\frac{1}{2}$	6	5·950	—	5·834	—	11
6	$6\frac{1}{2}$	6·450	—	6·334	—	11

Radii to which $1\frac{1}{2}$-**in.** wide Flats can be bent *on the flat.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches* ($\frac{1}{32}$ $\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10)
20 g.	0·2	← - - 1149 - - → ← - - 1 - → ← - - - 2 - - - → ← - - - 2 A - - - →
18 g.	0·25	← - - 1149 - - → ← - - 1 - → ← - - - 2 - - - → ← - - - 2 A - - - →
16 g.	0·318	← - - 1149 - - → ← - - 1 - → ← - - - 2 - - - → ← - - - 2 A - - - →
14 g.	0·400	← - - 1149 - - → ← - - 1 - → ← - - - 2 - - - → ← - - - 2 A - - - →
12 g.	0·505	← - 114 9 → ← - - 1 - → ← - - - 2 - - - → ← - - - 2 A - - - →
$\frac{1}{8}$ in.	0·64	← - 114 9 → ← - - 1 - → ← - - - 2 - - → ← - - - 2 A - - - →
$\frac{3}{16}$ in.	0·95	← - 114 9 → ← - 1 → ← - - - 2 - - → ← - - - 2 A - - - →
$\frac{1}{4}$ in.	1·28	← - 114 9 → ← - - - 2 - - → ← - - - 2 A - - - → ← - - - 4 - - - →
$\frac{5}{16}$ in.	1·59	← 11 49 → ← - - - 2 - - → ← - - - 2 A - - - → ← - - - 4 - - - →
$\frac{3}{8}$ in.	1·91	← - - - 2 - - → ← - - - 2 A - - - → ← - - - 4 - - - →
$\frac{1}{2}$ in.	2·55	← - - - 2 A - - - → ← - - - 4 - - - →
$\frac{5}{8}$ in.	3·19	← - - - 2 A - - - → ← - - - 4 - - - →
$\frac{3}{4}$ in.	3·83	← - - - 2 A - - - → ← - - - 4 - - - →
$\frac{7}{8}$ in.	4·46	← - - - 2 A - - - → ← - - - 4 - - - →
1 in.	5·1	← - - - 4 - - - →
$1\frac{1}{4}$ in	6·38	← - - - 4 - - - →

Radii to which **$1\frac{3}{4}$-in.** wide Flats can be bent *on the flat.*

Radius in Inches: $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, $6\frac{1}{2}$, 7, 8, 9, 10

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*
16 g.	0·372	← 1149 → ; ← -2 AU → ; ← -2 →
14 g.	0·467	← 1149 → ; ← -2 AU → ; ← -2 →
$\frac{1}{8}$ in.	0·745	← 1149 → ; ← -2 AU → ; ← -2 →
$\frac{3}{16}$ in.	1·12	← 1149 → ; ← -2 AU → ; ← -2 →
$\frac{1}{4}$ in.	1·49	1149 ; ← -2 AU → ; ← -2 G →
$\frac{5}{16}$ in.	1·86	← -2 AU → ; ← -4 →
$\frac{3}{8}$ in.	2·23	← -2 AU → ; ← 4 →
$\frac{1}{2}$ in.	2·98	← 4 →
$\frac{5}{8}$ in.	3·72	← 4 →
$\frac{3}{4}$ in.	4·46	← 4 →
$\frac{7}{8}$ in.	5·21	← 4 →
1 in.	5·95	← 4 →
$1\frac{1}{4}$ in.	7·44	← 4 →
$1\frac{1}{2}$ in.	8·93	← 4 →

Radii to which **2-in.** wide Flats can be bent *on the flat.*

Radius in Inches: $\frac{1}{32}$, $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, 5, $5\frac{1}{2}$, 6, $6\frac{1}{2}$, 7, 8, 9, 10

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*
18 g.	0·337	← 1149 → ; ← -2 →
16 g.	0·425	← 1149 → ; ← -2 →
14 g.	0·434	← 1149 → ; ← -2 →
$\frac{1}{8}$ in.	0·85	← 1149 → ; ← -2 →
$\frac{3}{16}$ in.	1·28	← 1149 → ; ← -2 G →
$\frac{1}{4}$ in.	1·7	1149 ; ← -2 AU → ; ← 4 →
$\frac{5}{16}$ in.	2·13	← -2 AU → ; ← 4 →
$\frac{3}{8}$ in.	2·55	← 4 →
$\frac{1}{2}$ in.	3·4	← 4 →
$\frac{5}{8}$ in.	4·25	← 4 →
$\frac{3}{4}$ in.	5·1	← 4 →
$\frac{7}{8}$ in.	5·95	← 4 →
1 in.	6·8	← 4 →
$1\frac{1}{4}$ in.	8·5	← 4 →
$1\frac{1}{2}$ in.	10·2	← 4 →

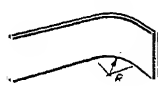
Radii to which $2\frac{1}{4}$-**in.** wide Flats can be bent *on the flat.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*	
		$\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1	$1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10
16 g.	0·478	← -114 9 →	← - - -2 - - - →
			← - - - - - - - - -2 AU - - - →
14 g.	0·600	← -114 9 →	← - - -2 - - - →
			← - - - - - - -2 AU - - - →
$\frac{1}{8}$ in.	0·96	←11 49→	← - - -2 - - →
			← - - - - - - -2 AU - - - →
$\frac{3}{16}$ in.	1·44	1149	← - - - - - - -2 AU - - - →
$\frac{1}{4}$ in.	1·91		← - - - - - - - - - - -4 - - - - - - - - - - →
$\frac{5}{16}$ in.	2·39		← - - - - - - - - - - -4 - - - - - - - - - - →
$\frac{3}{8}$ in.	2·87		← - - - - - - - - - - -4 - - - - - - - - - - →
$\frac{1}{2}$ in.	3·83		← - - - - - - - - - 4 - - - - - - - - - - →
$\frac{5}{8}$ in.	4·78		← - - - - - - - - -4 - - - - - - - - - →
$\frac{3}{4}$ in.	5·74		← - - - - - - -4 - - - - - - - →

Radii to which $2\frac{1}{2}$-**in.** wide Flats can be bent *on the flat.*

Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*	
		$\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1	$1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10
16 g.	0·531	← -114 9 →	← - - -2 - - →
14 g.	0·667	← -114 9 →	← - - -2 - - →
			← - - - - - - - - -2 AU - - - →
$\frac{1}{8}$ in.	1·06	←11 49→	← - -2 - →
			← - - - - - - - - -2 AU - - - →
$\frac{1}{4}$ in.	2·13		← - - - - - - - - -2 AU - - - →
$\frac{1}{2}$ in.	4·25		← - - - - - - - - - -4 - - - - - - - - - →
$\frac{3}{4}$ in.	6·38		← - - - - - - - -4 - - - - - - - →

Radii to which 3-**in.** wide Flats can be bent *on the flat.*



Thickness of Strip	*Weight in lb. per ft.*	*Radius in Inches*	
		$\frac{1}{16}$ $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1	$1\frac{1}{2}$ 2 $2\frac{1}{2}$ 3 $3\frac{1}{2}$ 4 $4\frac{1}{2}$ 5 $5\frac{1}{2}$ 6 $6\frac{1}{2}$ 7 8 9 10
16 g.	0·638	← -114 9 →	← - - - - - - -2 AU - - - →
14 g.	0·801	←11 49→	← - - - - - - -2 AU - - - →
$\frac{1}{8}$ in.	1·26	1149	← - - - - - - -2 AU - - - →
$\frac{1}{4}$ in.	2·55		← - - - - - - -2 AU - - - →
			← - - - - - - - - - - 4 - - - - - - - - - - →
$\frac{1}{2}$ in.	3·83		← - - - - - - - - -4 - - - - - - - →

Multiple Bending M.S. Flat Bars on Edge Cold

Table showing number of Flat Bars that can be bent on edge simultaneously on suitable Kennedy Benders.

Size of Bar	Bending Machine No. 1U	2U	2GU	2AU	3AU
½ in. × 1/16 in. ..	10	14	14	22	32
½ in. × ⅛ in. ..	5	6	6	11	16
½ in. × 3/16 in. ..	3	4	4	7	10
½ in. × ¼ in. ..	2	3	3	6	8
½ in. × ⅜ in. ..	1	2	2	5	6
⅝ in. × 1/16 in. ..	9	14	14	20	24
⅝ in. × ⅛ in. ..	4	7	7	10	12
⅝ in. × 3/16 in. ..	3	5	5	7	8
⅝ in. × ¼ in. ..	2	3	3	5	6
⅝ in. × ⅜ in. ..	1	2	2	3	4
⅝ in. × ½ in. ..	1	1	1	2	3
¾ in. × 1/16 in. ..	5	12	12	16	24
¾ in. × ⅛ in. ..	2	6	6	8	12
¾ in. × 3/16 in. ..	1	4	4	5	8
¾ in. × ¼ in. ..	1	3	3	4	6
¾ in. × 5/16 in. ..	1	2	2	3	4
¾ in. × ⅜ in. ..	—	2	2	2	4
¾ in. × ½ in. ..	—	1	1	2	2
¾ in. × ⅝ in. ..	—	1	1	1	2
⅞ in. × 1/16 in. ..	4	10	10	14	24
⅞ in. × ⅛ in. ..	2	5	5	7	12
⅞ in. × 3/16 in. ..	1	3	3	5	8
⅞ in. × ¼ in. ..	1	2	2	3	6
⅞ in. × ⅜ in. ..	—	1	1	2	4
⅞ in × ½ in. ..	—	—	—	1	3
⅞ in. × ⅝ in. ..	—	—	—	1	2
1 in. × 1/16 in. ..	2	10	10	12	18
1 in. × ⅛ in. ..	1	5	5	6	9
1 in. × 3/16 in. ..	1	3	3	4	6
1 in. × ¼ in. ..	—	2	2	3	4
1 in. × 5/16 in. ..	—	1	1	2	3
1 in. × ⅜ in. ..	—	1	1	2	3
1 in. × ½ in. ..	—	—	—	2	3
1 in. × ⅝ in. ..	—	—	—	1	2
1 in. × ¾ in. ..	—	—	—	—	1

MULTIPLE BENDING M.S. FLAT BARS ON EDGE COLD—*continued*

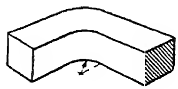
Size of Bar	*Bending Machine No.*				
	1U	*2U*	*2GU*	*2AU*	*3AU*
1¼ in. 11/16 ⅛ in. ..	—	2	2	3	4
1¼ in. × 3/16 in. ..	—	1	1	2	3
1¼ in. × ¼ in. ..	—	1	1	1	2
1¼ in. × ⅜ in. ..	—	—	—	1	2
1¼ in. × ½ in. ..	—	—	—	—	1
1¼ in. × ⅝ in. ..	—	—	—	—	1
1¼ in. × ¾ in. ..	—	—	—	—	1
1⅜ in. × ¼ in. ..	—	1	1	2	2
1⅜ in. × ⅜ in. ..	—	—	—	1	2
1⅜ in. × ½ in. ..	—	—	—	1	1
1½ in. × ⅛ in. ..	—	—	—	2	3
1½ in. × ¼ in. ..	—	—	—	1	2
1½ in. × ⅜ in. ..	—	—	—	1	2
1½ in. × ½ in. ..	—	—	—	1	1
1½ in. × ⅝ in. ..	—	—	—	1	1
1½ in. × ¾ in. ..	—	—	—	—	1
1½ in. × ⅞ in. ..	—	—	—	—	1
1½ in. × 1 in. ..	—	—	—	—	1
2 in. × ⅛ in. ..	—	—	—	2	3
2 in. × 3/16 in. ..	—	—	—	1	2
2 in. × ¼ in. ..	—	—	—	1	2
2 in. × 5/16 in. ..	—	—	—	—	1
2 in. × ½ in. ..	—	—	—	—	1

WEIGHTS OF SHEET METAL, ETC.
Lb. per Foot Super

Material	*Thickness*	
	1/16 in.	*1 in.*
Steel	2·55	40·8
Wrought iron	2·50	40·0
Cast iron.	2·35	37·5
Copper	2·86	45·8
Lead	3·71	59·4
Zinc	2·34	37·5
Brass	2·74	43·9
Window glass	0·81	13·0
Compact slate	0·94	15·0

TABLE SHOWING VARIOUS RADII TO WHICH M.S. SQUARE BARS CAN BE BENT COLD WITH SUITABLE TYPES OF BENDING MACHINES IN EACH CASE

Suitable types of Kennedy Bending Machines and various Radii to which M.S. Square Bars may be bent *cold.*



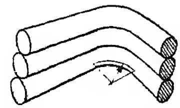
Size of Square Bar	*Weight in lb. per ft.*	*Radius in Inches* (1/32, 1/16, 1/8, 1/4, 1/2, 1, 1½, 2, 2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7)
in.		
3/16	0·12	←---1 149---→ ←---1 212---→
		←--------1 213--------→
¼	0·213	←---1 149---→ ←---1 212---→
		←--------1 213--------→
5/16	0·332	←---1 149---→ ←---1 212---→
		←--------1 213--------→
⅜	0·478	←--1149--→ ←---1 212---→
		←--------1 213--------→
7/16	0·651	←1149→ ←---1 212---→
		←--------1 213--------→
½	0·85	←---1 212---→
		←--------1 213--------→
9/16	1·076	←---1 212---→
		←--------1 213--------→
⅝	1·328	←--------1 213--------→
11/16	1·607	←--------1 213--------→
¾	1·912	←--------1 213--------→
		←----------2A----------→
⅞	2·603	←--------1 213--------→
		←----------2A----------→
1	3·4	←----------2A----------→
1⅛	4·303	←----------2A----------→
1¼	5·312	←--------2A--------→
		←----------4----------→
1⅜	6·428	←----------4----------→
1½	7·65	←----------4----------→
1⅝	8·978	←--------4--------→
1¾	10·413	←------3------→

TABLE SHOWING VARIOUS RADII TO WHICH M.S. ROUND BARS CAN BE BENT COLD WITH SUITABLE TYPES OF BENDING MACHINES IN EACH CASE

Suitable size Kennedy Bar Benders and various Radii to which M.S. Round Bars may be bent *cold*.

Radius in Inches: 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1¼, 1½, 1¾, 2, 2½, 3, 3½, 4, 4½, 5, 5½, 6, 6½, 7, 7½, 8, 8½, 9

Diameter of Bar	*Weight in lb. per ft.*	*Radius in Inches*
in.		
3/16	0·094	← -114 9 → ← -1 21 2 - →
		← - - - - -1 21 3 - - - - - →
1/4	0·167	← -114 9 → ← -1 21 2 - →
		← - - - - -1 21 3 - - - - - →
3/8	0·376	←11 49→ ← -1 21 2 - →
		← - - - - 12 13 - - - - →
1/2	0·668	← -1 21 2 - →
		← - - - - 12 13 - - - - →
		← - - - - - - - - - - - - -2 A - - - - - - - - - - - - - - →
5/8	1·043	← -1 21 2 - →
		← - - - - 12 13 - - - - →
		← - - - - - - - - - - - - -2 A - - - - - - - - - - - - - - →
3/4	1·502	← - - - - 12 13 - - - - →
		← - - - - - - - - - - - - -2 A - - - - - - - - - - - - - - →
		← - - - - - - - - - - - - - - - - 4 - - - - - - - - - - - - - - - - - →
7/8	2·044	← - - - -1 21 3 - - - →
		← - - - - - - - - - - - - -2 A - - - - - - - - - - - - →
		← - - - - - - - - - - - - - - - - 4 - - - - - - - - - - - - - - - - - →
1	2·67	← - - - -1 21 3 - - - →
		← - - - - - - - - - - - -2 A - - - - - - - - - - - - →
		← - - - - - - - - - - - - - - - - 4 - - - - - - - - - - - - - - - - - →
1⅛	3·38	← - - - - - - - - - - - -2 A - - - - - - - - - - →
		← - - - - - - - - - - - - - - - -4 - - - - - - - - - - - - - - →
1¼	4·17	← - - - - - - - - - - - -2 A - - - - - - - - - - →
		← - - - - - - - - - - - - - - - -4 - - - - - - - - - - - - - - →
1⅜	5·05	← - - - - - - - - - - - -2 A - - - - - - - - - - →
		← - - - - - - - - - - - - - - - -4 - - - - - - - - - - - - - - →
1½	6·01	← - - - - - - - - - - - -2 A - - - - - - - - - - →
		← - - - - - - - - - - - - - -4 - - - - - - - - - - - - - - →
1⅝	7·05	← - - - - - - - - - - - - 4 - - - - - - - - - - - - - →
1¾	8·18	← - - - - - - - - - - 4 - - - - - - - - - - - - →
1⅞	9·39	← - - - - - - - -4 - - - - - - - →
2	10·68	← - - - - 4 - - - →



Multiple Bending M.S. Bars Cold

Table showing number of round bars that can be bent simultaneously on suitable Kennedy Bar Benders.

Size of Bar	Bending Machine No.						
	1212 *Standard*	1212 *with Extra Roller*	1213 *Standard*	1213 *with Extra Rollers*	2A *Standard*	2A *with Extra Former*	4 *Standard*
in.							
3/16	3	6	4	9	6	10	16
1/4	2	4	3	8	4	8	12
5/16	2	4	2	6	3	6	10
3/8	1	2	2	5	3	6	8
7/16	1	2	2	4	3	5	7
1/2	1	1	1	3	2	4	6
5/8	1	1	1	2	1	3	5
3/4	—	—	1	1	1	3	4
7/8	—	—	1	1	1	3	3
1	—	—	—	1	1	2	3
1 1/8	—	—	—	—	1	2	2
1 1/4	—	—	—	—	1	1	2
1 3/8	—	—	—	—	1	1	1
1 1/2	—	—	—	—	1	1	1
1 3/4	—	—	—	—	—	—	1
2	—	—	—	—	—	—	1

BENDING BARS IN QUANTITIES

It is sometimes possible to adapt a bending machine to bend bars in quantities by means of an attachment to the last pair of rolls, as, by using a roller to bend, and a slotted roller above it, the final dimensions can be made accurate. This ensures that the metal will not be damaged in any way while, as the bars are short, no twist will be necessary, and subsequent cold straightening can be avoided.

A machine of the type used in shipyards would be capable of bending the material cold in one pass, and there are slip bands due to the cold working. These might become planes of cleavage and cause cracks in the web, which, of course, would thicken. Also, to get the metal to yield sufficiently the operation would have to be done at a very high speed, probably necessitating more than one set of driving rolls, to obtain enough grip. This could be accomplished hot, but the dimensions would have to be less after the process, and in all cases there will be a little scrap at the start, unless the end is taken round a forming block, or smithed, or pressed. If the job is performed hot, the use of a forming block provides a quick way of obtaining the desired result, although a little smithing of the web would be necessary.

If cold working cannot be done at sufficient speed with the plant available, several more-gradual passes will be necessary but, the forces employed being smaller, less restraint may be needed.

In bending work it very often happens that the natural springiness of the material necessitates the piece being bent farther than is actually required, to allow for the amount of spring. Certain soft metals, such as some of the aluminium alloys and soft brass, do sometimes remain as they are bent, but hard brass and steel usually have to be bent at least 50 degrees or more to obtain an angle of 45 degrees. For this reason punches and dies are usually tried out in the soft state, and any alterations made to the form before hardening.

The trial of all bending and forming tools should be conducted under the same conditions as those under which the tool will have to work when finished, if possible in the same press or type of press, as the speed of the stroke and the pressure applied often have an influence on the result.

Table showing Various Radii to which M.S. Angle can be Bent Web In or Web Out, Cold, with Suitable Types of Bending Machines in each Case

Suitable types of Kennedy Bending Machines and Various Radii to which M.S. Angle may be bent *cold.*

WEB IN 

 WEB OUT

Size of Angle in Inches	*Weight in lb. per ft.*	*Radius in Inches*: 2¼ 2½ 3 3¼ 3½ 3¾ 4 4¼ 4½ 4¾ 5 5¼ 5½ 5¾ 6 6½ 7 7½ 8 8½ 9
$\frac{5}{8} \times \frac{5}{8} \times \frac{1}{8}$	0·48	← - - 2 - - →
		← - - - - - - - 2 AU - - - - - - - →
		← - - - - - - - 3 A - - - - - - - →
$\frac{3}{4} \times \frac{3}{4} \times \frac{1}{8}$	0·58	← - - 2 - - →
		← - - - - - - - 2 AU - - - - - - - →
		← - - - - - - - 3 A - - - - - - - →
$\frac{7}{8} \times \frac{7}{8} \times \frac{1}{8}$	0·69	← - - 2 - →
		← - - - - - - - 2 AU - - - - - - - →
		← - - - - - - - 3 A - - - - - - - →
$1 \times 1 \times \frac{1}{8}$	0·80	← - - 2 - →
		← - - - - - - 2 AU - - - - - - - →
		← - - - - - - - 3 A - - - - - - - →
$1 \times 1 \times \frac{3}{16}$	1·16	← - - 2 - →
		← - - - - - - 2 AU - - - - - - - →
		← - - - - - - - 3 A - - - - - - - →
$1 \times 1 \times \frac{1}{4}$	1·49	← - - 2 - →
		← - - - - - - 2 AU - - - - - - - →
		← - - - - - - - 3 A - - - - - - - →
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{8}$	1·02	← - - - - - - 2 AU - - - - - - →
		← - - - - - - 3 A - - - - - - - →
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{3}{16}$	1·47	← - - - - - - 2 AU - - - - - - →
		← - - - - - - 3 A - - - - - - - →
$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{4}$	1·92	← - - - - - - 2 AU - - - - - - →
		← - - - - - - 3 A - - - - - - - →
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{8}$	1·23	← - - - - - - 2 AU - - - - - →
		← - - - - - - 3 A - - - - - - →
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{3}{16}$	1·79	← - - - - - - 2 AU - - - - - →
		← - - - - - - 3 A - - - - - - →
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{4}$	2·34	← - - - - - - 2 AU - - - - - →
		← - - - - - - 3 A - - - - - - →
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{5}{16}$	2·86	← - - - - - - 3 A - - - - - - →
$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{3}{8}$	3·35	← - - - - - - 3 A - - - - - - →
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{3}{16}$	2·11	← - - - - 3 A - - - - - →
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{1}{4}$	2·76	← - - - - 3 A - - - - →
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{5}{16}$	3·39	← - - - 3 A - - - - →
$1\frac{3}{4} \times 1\frac{3}{4} \times \frac{3}{8}$	3·98	← - - - 3 A - - - →
$2 \times 2 \times \frac{3}{16}$	2·43	← - - - 3 A - - →
$2 \times 2 \times \frac{1}{4}$	3·19	← - - - 3 A - - →
$2 \times 2 \times \frac{5}{16}$	3·92	← - - 3 A - - →

TABLE SHOWING VARIOUS RADII TO WHICH M.S. TEES CAN BE BENT COLD WITH SUITABLE TYPES OF BENDING MACHINES IN EACH CASE

Suitable types of Kennedy Bending Machines and various Radii to which M.S. Tees may be bent *cold.*

WEB UP WEB IN WEB OUT

Size of Tee in Inches	*Weight in lb. per ft.*	*Radius in Inches* 1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	6½	7	7½	8
$\frac{5}{8}\times\frac{5}{8}\times\frac{1}{8}$	0·49	←		1		→	←		2			→								
$\frac{3}{4}\times\frac{3}{4}\times\frac{1}{8}$	0·59	←		1		→	←		2			→								
$1\times1\times\frac{1}{8}$	0·82						←		2			→								
$1\times1\times\frac{3}{16}$	1·17						←		2			→								
$1\times1\times\frac{1}{4}$	1·54						←		2			→								
$1\frac{1}{4}\times1\frac{1}{4}\times\frac{3}{16}$	1·49						←		2			→								
$1\frac{1}{4}\times1\frac{1}{4}\times\frac{1}{4}$	1·93											←			2 AU					→
$1\frac{1}{2}\times1\frac{1}{2}\times\frac{3}{16}$	1·81											←			2 AU				→	
$1\frac{1}{2}\times1\frac{1}{2}\times\frac{1}{4}$	2·35											←			2 AU				→	
$1\frac{3}{4}\times1\frac{3}{4}\times\frac{3}{16}$	2·14										←			3 A					→	
$1\frac{3}{4}\times1\frac{3}{4}\times\frac{1}{4}$	2·79											←			3 A				→	
$2\times2\times\frac{1}{4}$	3·22												←		3 A				→	
$2\times2\times\frac{5}{16}$	3·94												←		3 A				→	

COPPER, BRASS AND STEEL TUBE BENDING

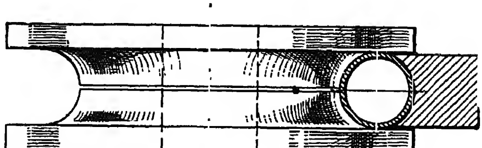
The following tables indicate the type of bending tool or former that should be used when bending to various radii. These formers are indicated as follows :

M = These bends should be made :
(1) On a machine using an inside mandrel.
Or (2) Suitably loaded and bent on an O former on a Universal Machine.

O = These bends should be made on an overlap former together with a grooved backformer.

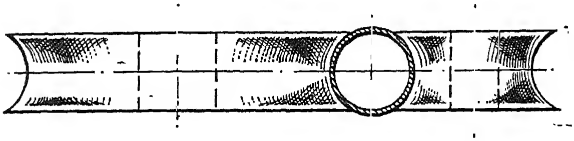
L = These must be loaded and bent on an O former.

Note.—On a suitable machine it is recommended that the O former should be split, with a slight clearance between the halves when the tube is in position (see diagram). This enables the tube to be pinched when the top plate is tightened. This improves the bend ; also a bend beyond 180° can be made.



OVERLAP FORMER (SPLIT TYPE)

G = Bends marked thus can be bent, on a suitable machine, using a semi-grooved former only and without a backformer. A semi-grooved roller is all that is required.



SEMI-GROOVED FORMER GROOVED ROLLER

F = These bends can usually be made without protection, and can be bent round any flat former of suitable size, if only a few off are required. If the quantity warrants it, use a grooved former.

RIVET SPACING

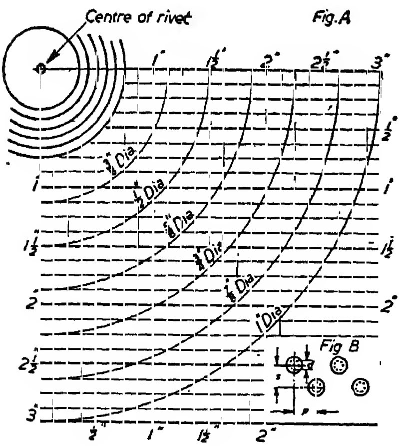
The diagrams show limiting positions for the centres of adjacent rivets of various diameters

The circular arcs in Fig. A below show the closest allowable positions of the centre of a rivet in relation to an adjacent rivet (shown in the top left-hand corner of the diagram) when the distance centre to centre is to be not less than 3 times the diameter—this being the minimum usually observed in structural work.

If the rivets are staggered, as in the inset Fig. B, and the foregoing rule is to be observed, the diagram will show at a glance the smallest allowable value for s for a given longitudinal half-pitch p, and conversely.

When rivets are used in the same plane through two flanges of an angle or tee, as in Fig. C, $\frac{1}{4}$-in. clearance, as shown therein, must be allowed for machine driving.

The diameter of the rivets being known, the lowest permissible value for x. can be read at a glance from Fig. D below. This diagram shows the closest permissible position for the centre of the second rivet, being along the circular arcs and straight lines continuing them.



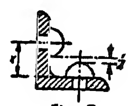
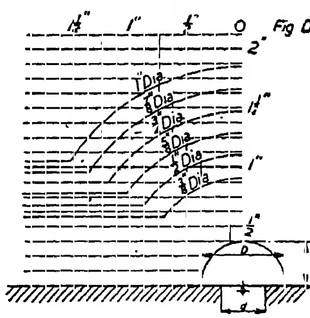
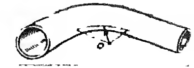


Fig. C.



$\frac{3}{8}$-in. O.D.



Gauge	Bore	Weight in lb. per ft.			Radius in Inches																					
		Brass	Copper	Steel	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·331	0·09	0·094	0·083	←	L→	←		M		→	←							O							→
23	0·327	0·098	0·102	0·091	←		M		→	←								O								→
22	0·319	0·113	0·118	0·104	←	M→	←								O									→	←	G→
21	0·311	0·128	0·133	0·121	L	←	M	→	←							O								→	←	G→
20	0·303	0·14	0·15	0·131	←	M	→	←							O							→	←		G	→
19	0·295	0·16	0·16	0·142	←	M→	←								O							→	←		G	→
18	0·279	0·18	0·19	0·169	M	←								O								→	←		G	→
17	0·263	0·21	0·21	0·190	M	←							O								→	←		G		→
16	0·247	0·23	0·24	0·213	M	←							O								→	←		G		→
15	0·231	0·25	0·27	0·233	←						O							→	←				G			→

$\frac{1}{2}$-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches																					
		Brass	Copper	Steel	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·456	0·123	0·127	0·115	←			L			→	←							O							→
23	0·452	0·133	0·138	0·123	←			L			→	←							O							→
22	0·444	0·154	0·16	0·143	←	L→	←	M	→	←							O							→	←	G→
21	0·436	0·174	0·181	0·166	←	L→	←	M	→	←							O							→	←	G→
20	0·428	0·19	0·2	0·18	←	M	→	←								O						→	←		G	→
19	0·42	0·21	0·22	0·199	←	M	→	←								O						→	←		G	→
18	0·404	0·25	0·26	0·234	←	M→	←							O							→	←		G		→
17	0·388	0·29	0·3	0·269	←	M→	←							O							→	←		G		→
16	0·372	0·32	0·34	0·301	M	←							O							→	←		G			→
15	0·356	0·36	0·38	0·334	M	←						O						→	←			G				→

$\frac{5}{8}$-in. O.D.

Gauge	Bore	Weight in lb. per ft. Brass	Copper	Steel	Radius in Inches $\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·581	0·154	0·16	0·142	←		L			→	M	←							O							→
23	0·577	0·168	0·174	0·156	←		L			→	M	←							O							→
22	0·569	0·195	0·202	0·179	←	L		→	←	M→	←							O								→
21	0·561	0·221	0·229	0·209	←	L	→	←	M	→	←							O								→
20	0·573	0·25	0·26	0·228	←	L→	M	←								O								→	←	G→
19	0·545	0·27	0·28	0·25	←	L→	M	←								O								→	←	G→
18	0·529	0·32	0·33	0·298	L	M	←								O							→	←		G	→
17	0·513	0·37	0·38	0·341	←	M→	←							O							→	←		G		→
16	0·497	0·42	0·43	0·384	←	M→	←							O							→	←		G		→
15	0·481	0·46	0·49	0·427	←	M→	←							O							→	←		G		→
14	0·465	0·51	0·53	0·468	M	←							O							→	←		G			→

$\frac{3}{4}$-in. O.D.

Gauge	Bore	Weight in lb. per ft. Brass	Copper	Steel	Radius in Inches $\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·707	0·187	0·194	0·172							←							M							→
23	0·702	0·203	0·211	0·188							←							M							→
22	0·694	0·236	0·245	0·217						←								M							→
21	0·686	0·268	0·278	0·255						←								M							→
20	0·678	0·3	0·31	0·277			L	←						M					→	←			O		→
19	0·67	0·33	0·34	0·306										←					O						→
18	0·654	0·39	0·40	0·363	←	L		→	←	M	→	←							O						→
17	0·638	0·45	0·47	0·416	←	L	→	←		M	→	←							O						→
16	0·622	0·51	0·53	0·473	←		M		→	←		O			→	←					G				→
15	0·606	0·57	0·6	0·574	←		M		→	←		O			→	←					G				→
14	0·590	0·62	0·65	0·575	M	←				O				→	←					G					→
13	0·576	0·7	0·74	0·650	M	←				O				→	←					G					→

$\frac{7}{8}$-in. O.D.

Gauge	Bore	Weight in lb. per ft. Brass	Copper	Steel	Radius in Inches $\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·831	0·219	0·227	0·201					←					L				→	←			M			→
23	0·827	0·238	0·247	0·22					←				L			→	←				M				→
22	0·819	0·276	0·287	0·255			←				L			→	←					M					→
21	0·811	0·314	0·326	0·298			←		L		→	←						M							→
20	0·803	0·35	0·37	0·325			←	L	→	←						M					→	←		O	→
19	0·795	0·39	0·4	0·357			←	L →	←			M			→	←				O					→
18	0·779	0·46	0·48	0·427		← L	→	←		M		→	←						O						→
17	0·763	0·53	0·55	0·492	←	L →	←			M		→	←						O						→
16	0·747	0·6	0·63	0·556	←			M			→	←						O					G		→
15	0·731	0·67	0·70	0·621	←			M			→	←				O			→	←					→
14	0·715	0·74	0·77	0·683	←	M	→	←				O				→	←				G				→
13	0·691	0·84	0·88	0·774	←	M	→	←				O			→	←					G				→
12	0·667	0·93	0·97	0·863	←	M	→	←		O		→	←						G						

1-in. O.D.

Gauge	Bore	Weight in lb. per ft. Brass	Copper	Steel	Radius in Inches $\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·956	0·251	0·26	0·234														←			M				→
23	0·952	0·273	0·283	0·252											←					M					→
22	0·944	0·317	0·329	0·293									←						M						→
21	0·936	0·361	0·375	0·344								←							M						→
20	0·928	0·4	0·42	0·373							←					M					→	←		O	→
19	0·92	0·45	0·46	0·414						←			M		→	←					O				→
18	0·904	0·53	0·55	0·493				←			M		→	←						O					→
17	0·888	0·62	0·63	0·57			←			M			→	←						O					→
16	0·872	0·7	0·72	0·645		←			M			→	←						O						→
15	0·856	0·78	0·81	0·721		←		M		→	←							O							→
14	0·84	0·86	0·89	0·793		←	M	→	←					O				→	←			G			→
13	0·816	0·97	1·01	0·901		←	M	→	←					O				→	←			G			→
12	0·792	1·08	1·13	1·003		←	M	→	←			O			→	←					G				→
11	0·768	1·19	1·24	1·105	←			M				→	←						G						

1⅛-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches																				
		Brass	Copper	Steel	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
24	1·081	0·283	0·292	0·26															←	- - -	- - -	M	- - -	- - -	→
23	1·077	0·308	0·32	0·285												←	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	→
22	1·069	0·358	0·372	0·330										←	- - -	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	- - -	→
21	1·061	0·407	0·423	0·387									←	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	- - -	→	←	O →
20	1·053	0·46	0·48	0·422								←	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	O	→
19	1·045	0·5	0·52	0·465							←	- - -	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	- - -	O	- - -	→
18	1·029	0·6	0·62	0·556						←	- - -	- - -	M	- - -	- - -	→	←	- - -	- - -	- - -	O	- - -	- - -	- - -	→
17	1·013	0·7	0·72	0·642				←	- - -	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	- - -	- - -	O	- - -	- - -	- - -	→
16	0·997	0·79	0·82	0·728			←	- - -	- - -	- - -	M	- - -	- - -	→	←	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→
15	0·981	0·88	0·92	0·815			←	- - -	- - -	M	- - -	- - -	→	←	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→
14	0·965	0·97	1·02	0·898			←	- - -	M	- - -	→	←	- - -	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	- - -	→
13	0·941	1·11	1·15	1·022			←	- - -	M	- - -	→	←	- - -	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	- - -	→
12	0·917	1·24	1·29	1·143			←	- - -	M	- - -	→	←	- - -	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	- - -	→
11	0·893	1·36	1·41	1·258			←	- - -	M	- - -	→	←	- - -	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	- - -	→

1¼-in. O.D.

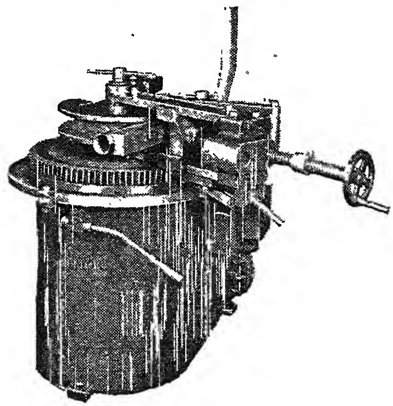
Gauge	Bore	Weight in lb. per ft.			Radius in Inches																				
		Brass	Copper	Steel	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
22	1·194	0·399	0·414	0·368															←	- - -	- - -	M	- - -	- - -	→
21	1·186	0·454	0·471	0·433													←	- - -	- - -	- - -	M	- - -	- - -	- - -	→
20	1·178	0·51	0·53	0·47									←	- - -	- - -	M	- - -	- - -	- - -	- - -	- - -	→	←	O	→
19	1·147	0·56	0·58	0·521							←	- - -	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	- - -	→	←	O	→
18	1·154	0·67	0·69	0·621						←	- - -	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	- - -	O	- - -	- - -	→
17	1·138	0·78	0·8	0·718					←	- - -	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	- - -	- - -	O	- - -	- - -	→
16	1·122	0·88	0·92	0·817			←	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	- - -	→	←	- - -	- - -	- - -	O	- - -	- - -	→
15	1·106	0·99	1·03	0·911			←	- - -	- - -	- - -	- - -	M	- - -	- - -	- - -	- - -	→	←	- - -	- - -	- - -	O	- - -	- - -	→
14	1·99	1·09	1·14	1·006			←	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→
13	1·966	1·24	1·29	1·145			←	- - -	- - -	M	- - -	- - -	- - -	→	←	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→
12	1·942	1·39	1·44	1·283			←	- - -	- - -	M	- - -	- - -	→	←	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→
11	1·918	1·53	1·59	1·414			←	- - -	- - -	M	- - -	- - -	→	←	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→
10	1·894	1·67	1·73	1·544			←	- - -	- - -	M	- - -	- - -	→	←	- - -	- - -	- - -	- - -	- - -	O	- - -	- - -	- - -	- - -	→

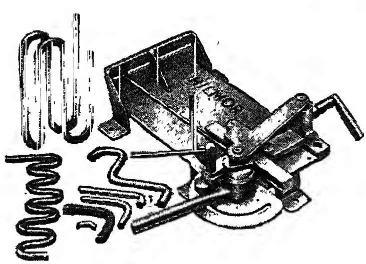
$1\frac{3}{8}$-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches																		
		Brass	Copper	Steel	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
20	1·303	0·56	0·58	0·519												←		M		→	←	O	→
19	1·295	0·62	0·64	0·572									←				M			→	←	O	→
18	1·279	0·74	0·89	0·685							←			M		→	←			O			→
17	1·263	0·86	1·01	0·743					←		M			→	←				O				→
16	1·247	0·98	1·14	0·901		←				M				→	←				O				→
15	1·231	1·09	1·26	1·008		←				M				→	←				O				→
14	1·215	1·21	1·43	1·113		←			M			→	←					O					→
13	1·191	1·37	1·6	1·269		←			M			→	←					O					→
12	1·167	1·54	1·76	1·423		←		M			→	←					O						→
11	1·143	1·7	1·93	1·57		←		M			→	←					O						→

$1\frac{1}{2}$-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches																		
		Brass	Copper	Steel	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
20	1·428	0·61	0·64	0·567												←			M		→	←	O →
19	1·42	0·68	0·7	0·629									←					M			→	←	O →
18	1·404	0·81	0·84	0·75						←					M				→	←	O		→
17	1·388	0·94	0·97	0·871				←						M					→	←	O		→
16	1·372	1·07	1·11	0·989		←					M					→	←			O			→
15	1·356	1·2	1·25	1·108		←					M					→	←			O			→
14	1·34	1·32	1·38	1·223		←				M				→	←				O				→
13	1·316	1·51	1·57	1·396		←				M				→	←				O				→
12	1·292	1·69	1·76	1·562		←			M				→	←				O					→
11	1·268	1·87	1·94	1·729		←			M				→	←				O					→
10	1·249	2·04	2·12	1·891		←		M	→	←		O	→	←				G					→
9	1·212	2·27	2·36	2·1		←		M	→	←	O	→	←					G					→





$1\frac{5}{8}$-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches																		
		Brass	Copper	Steel	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
20	1·553	0·67	0·69	—												←			M				→
19	1·545	0·74	0·77	—											←			M				→	O
18	1·529	0·88	0·91	—											←			M		→	←	O	→
17	1·513	1·02	1·06	0·944										←			M			→	←	O	→
16	1·497	1·16	1·21	1·073								←			M		→	←		O			→
15	1·481	1·3	1·36	1·202							←				M		→	←		O			→
14	1·465	1·44	1·5	1·338						←				M			→	←		O			→
13	1·441	1·64	1·71	1·517						←		M		→	←				O				→
12	1·417	1·84	1·91	1·702					←				M		→	←		O			→	← G	→
11	1·393	2·04	2·11	1·883					M	←					O				→	←	G		→
10	1·369	2·23	2·31	2·06					M	←					O			→	←		G		→
9	1·337	2·48	2·58	2·294					M	←			O			→	←			G			→
8	1·305	2·73	2·83	2·521					M	←		O		→	←				G				→

$1\frac{3}{4}$-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches														
		Brass	Copper	Steel	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
20	1·678	0·72	0·75	—												←		M	→
19	1·67	0·8	0·83	—								←			M				→
18	1·654	0·95	0·98	—							←			M			→	← O	→
17	1·638	1·1	1·14	1·019						←				M			→	← O	→
16	1·622	1·26	1·3	1·162					←				M			→	←	O	→
15	1·606	1·41	1·47	1·299					←			M			→	←	O		→
14	1·59	1·56	1·62	1·436					←		M			→	←		O		→
13	1·566	1·78	1·85	1·64					←		M		→	←		O			→
12	1·542	1·99	2·07	1·842					←		M	→	←			O			→
11	1·518	2·21	2·29	2·039				←		M		→	←			O			→
10	1·494	2·42	2·51	2·232			←		M			→	←			O			→
9	1·462	2·69	2·8	2·488			←		M			→	←			O			→
8	1·43	2·46	3·08	2·736			←		M			→	←			O			→

$1\frac{7}{8}$-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches														
		Brass	Copper	Steel	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
20	1·803	0·77	0·8	—											←		M		→
19	1·795	0·86	0·89	—										←		M			→
18	1·779	1·02	1·06	—									←		M		→	←	O →
17	1·763	1·19	1·23	1·094								←		M		→	←	O	→
16	1·747	1·35	1·4	1·245								←		M		→	←	O	→
15	1·371	1·51	1·58	1·396							←		M		→	←	O		→
14	1·715	1·67	1·74	1·544					←			M			→	←	O		→
13	1·691	1·91	1·99	1·764				←			M			→	←		O		→
12	1·667	2·14	2·23	1·982			←			M				→	←		O		→
11	1·643	2·38	2·46	2·195			←			M			→	←			O		→
10	1·619	2·6	2·7	2·404			←			M			→	←			O		→
9	1·587	2·9	3·02	2·681			←			M			→	←			O		→
8	1·555	3·19	3·32	2·952			←			M			→	←			O		→
7	1·523	3·48	3·62	3·216			←			M			→	←			O		→

2-in. O.D.

Gauge	Bore	Weight in lb. per ft.			Radius in Inches														
		Brass	Copper	Steel	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
20	1·928	0·83	0·86	—												←	M		→
19	1·92	0·91	0·95	—											←		M		→
18	1·904	1·1	1·13	—										←		M			→
17	1·888	1·27	1·31	1·172									←			M			→
16	1·872	1·44	1·5	1·334								←		M		→	←	O	→
15	1·856	1·62	1·68	1·495								←		M		→	←	O	→
14	1·84	1·79	1·86	1·654						←			M		→	←		O	→
13	1·816	2·04	2·13	1·891						←			M		→	←		O	→
12	1·792	2·3	2·39	2·172					←			M		→	←		O		→
11	1·768	2·54	2·64	2·353					←			M		→	←		O		→
10	1·744	2·79	2·89	2·579				←			M		→	←			O		→

¼-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: ⅝	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
24	0·072	0·294	M	←				O				→	←			G		→	←			F		→
23	0·080	0·298	M	←				O			→	←			G		→	←			F			→
22	0·094	0·306	M	←				O			→	←			G		→	←			F			→
21	0·109	0·314	M	←				O			→	←			G		→	←			F			→
20	0·12	0·332	M	←			O			→	←			G		→	←				F			→
19	0·14	0·33	M	←			O			→	←		G		→	←				F				→
18	0·17	0·346	M	←			O			→	←		G		→	←				F				→
17	0·21	0·362	M	←			O			→	←		G		→	←				F				→
16	0·24	0·378	M	←			O			→	←		G		→	←				F				→
15	0·28	0·394	←			O		→	←			G		→	←					F				→
14	0·32	0·41	←		O	→	←			G			→	←					F					→
13	0·38	0·424	←	O	→	←			G			→	←						F					→
12	0·44	0·458	←	O	→	←			G		→	←						F						→

⅜-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: ⅝	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
24	0·106	0·419			←		M	→	←								O							→
23	0·116	0·423			←	M→	←									O								→
22	0·137	0·431	←	M	→	←									O									→
21	0·158	0·439	←	M	→	←									O									→
20	0·18	0·447	←	M	→	←									O									→
19	0·20	0·455	←	M	→	←				O				→	←			G					→	F
18	0·25	0·471	←	M	→	←				O			→	←				G			→	←	F	→
17	0·29	0·487	←	M→	←				O			→	←			G			→	←		F		→
16	0·34	0·503	←	M→	←			O			→	←			G		→	←			F			→
15	0·39	0·519	←	M→	←			O		→	←		G		→	←				F				→
14	0·44	0·535	←	M→	←		O		→	←		G	→	←					F					→
13	0·52	0·559	M	←		O		→	←		G	→	←						F					→
12	0·60	0·583	←		O		→	←		G	→	←						F						→
11	0·69	0·607	←		O	→	←	G	→	←							F							→
10	0·87	0·631	←		O	→	←	G→	←								F							→

$\frac{1}{2}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in. Inches	Radius in Inches $\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·139	0·544				←	- -	M	- -	→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	G	- -	→
23	0·152	0·548				←	M	- -	→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	G	- -	→
22	0·179	0·556				←	M	→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	G	- -	- -	→
21	0·206	0·564				←	M→	←	- -	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	G	- -	- -	→
20	0·23	0·572			←	M→	←	- -	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	G	- -	- -	→
19	0·26	0·58			←	M→	←	- -	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	G	- -	- -	→
18	0·32	0·596		←	M→	←	- -	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	G	- -	- -	- -	→
17	0·38	0·612		M	←	- -	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	- -	G	- -	- -	→	F
16	0·44	0·628	←	M→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	- -	G	- -	- -	- -	→	F
15	0·50	0·644	←	M→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	G	- -	- -	- -	→	←	F→
14	0·56	0·66	←	M→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	- -	G	- -	- -	→	←	F	→
13	0·66	0·684	←	M→	←	- -	- -	- -	O	- -	- -	- -	→	←	- -	- -	G	- -	- -	→	←	- -	F	→
12	0·76	0·708	←	M→	←	- -	- -	- -	O	- -	- -	→	←	- -	- -	G	- -	- -	→	←	- -	F	- -	→
11	0·86	0·732	←	M→	←	- -	- -	- -	O	- -	- -	→	←	- -	- -	G	- -	→	←	- -	- -	F	- -	→
10	0·97	0·756	←	M→	←	- -	- -	O	- -	- -	→	←	- -	- -	G	- -	→	←	- -	- -	F	- -	- -	→
9	1·12	0·788	←	M→	←	- -	- -	O	- -	- -	→	←	- -	G	- -	→	←	- -	- -	- -	F	- -	- -	→
8	1·28	0·82	M	←	- -	- -	O	- -	- -	→	←	- -	G	- -	→	←	- -	- -	- -	F	- -	- -	- -	→
7	1·44	0·852	←	- -	- -	- -	O	- -	- -	→	←	- -	G	→	←	- -	- -	- -	- -	F	- -	- -	- -	→
6	1·61	0·884	←	- -	- -	O	- -	- -	→	←	- -	G	→	←	- -	- -	- -	- -	F	- -	- -	- -	- -	→
5	1·83	0·924	←	- -	- -	O	- -	- -	→	←	G	→	←	- -	- -	- -	- -	- -	F	- -	- -	- -	- -	→
4	2·05	0·964	←	- -	- -	O	- -	→	←	G	→	←	- -	- -	- -	- -	- -	F	- -	- -	- -	- -	- -	→
3	2·29	1·004	←	- -	- -	O	- -	→	←	G→	←	- -	- -	- -	- -	- -	- -	F	- -	- -	- -	- -	- -	→

$\frac{5}{8}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches																				
			$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·172	0·669							←						M						→	← O	→
23	0·188	0·673							←						M					→	←	O	→
22	0·221	0·681				←						M						→	←	O	→	← G	→
21	0·254	0·689			←						M					→	←	O	→	←		G	→
20	0·29	0·697			←				M			→	←			O		→	←		G		→
19	0·32	0·705		←			M			→	←			O			→	←			G		→
18	0·39	0·721		←			M		→	←			O			→	←			G			→
17	0·46	0·737		←		M		→	←			O			→	←				G			→
16	0·53	0·753	←	M		→	←				O			→	←				G				→
15	0·61	0·769	←	M		→	←				O			→	←				G				→
14	0·68	0·785	←	M	→	←				O			→	←					G				→
13	0·80	0·809	←	M	→	←				O			→	←					G			→	F
12	0·92	0·833	←	M→	←				O			→	←				G				→	←	F→
11	1·04	0·857	←	M→	←				O			→	←				G			→	←	F	→
10	1·17	0·881	M	←				O			→	←				G			→	←		F	→
9	1·34	0·913	M	←				O			→	←			G			→	←		F		→
8	1·52	0·945	M	←			O			→	←			G			→	←			F		→
7	1·7	0·977	M	←			O			→	←			G		→	←			F			→
6	1·9	1·009	←			O			→	←			G		→	←				F			→
5	2·15	1·049	←			O			→	←		G		→	←				F				→
4	2·4	1·089	←			O		→	←		G		→	←					F				→
3	2·67	1·129	←			O		→	←		G	→	←					F					→
2	3·01	1·177	←		O	→	←		G		→	←						F					→
1	3·36	1·225	←		O	→	←		G	→	←						F						→

$\frac{3}{4}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: $\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·206	0·794											←					M					→
23	0·225	0·798										←						M					→
22	0·264	0·806									←						M					→	O
21	0·303	0·814								←						M						→	O
20	0·34	0·822							←					M					→	←	O→	←	G→
19	0·38	0·83						←			M		→	←				O			→	←	G→
18	0·46	0·846				←			M		→	←				O			→	←		G	→
17	0·55	0·862			←			M		→	←				O			→	←		G		→
16	0·63	0·878		←			M		→	←				O				→	←		G		→
15	0·72	0·894		←		M		→	←				O				→	←			G		→
14	0·80	0·91		←		M	→	←				O				→	←			G			→
13	0·94	0·934		←	M	→	←				O				→	←				G			→
12	1·07	0·958		←	M→	←				O				→	←				G				→
11	1·21	0·982		←	M→	←				O				→	←				G				→
10	1·36	1·006		M	←				O				→	←				G				→	F
9	1·56	1·038		M	←				O			→	←					G				→	F
8	1·76	1·07		←				O			→	←				G				→	←	F	→
7	1·97	1·102		←				O			→	←				G				→	←	F	→
6	2·19	1·134		←			O			→	←				G			→	←		F		→
5	2·47	1·174		←			O			→	←				G			→	←		F		→
4	2·76	1·214		←			O		→	←			G			→	←			F			→
3	3·05	1·254		←			O		→	←			G			→	←			F			→
2	3·43	1·298		←		O		→	←			G		→	←				F				→
1	3·81	1·35		←		O		→	←		G	→	←					F					→

$\frac{7}{8}$-in. Bore Copper Tubes

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: 1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
24	0·239	0·919													←				M			→
23	0·261	0·923											←					M				→
22	0·306	0·931								←						M						→
21	0·351	0·939							←						M							→
20	0·40	0·947					←						M					→	←	O	→	G
19	0·44	0·955				←			M			→	←				O			→	←	G→
18	0·54	0·971			←			M		→	←				O			→	←		G	→
17	0·63	0·987		←			M		→	←			O			→	←			G		→
16	0·73	1·003	←			M			→	←			O		→	←			G			→
15	0·82	1·019	←		M		→	←			O			→	←				G			→
14	0·92	1·035	←		M	→	←			O			→	←				G				→
13	1·08	1·059	←		M	→	←			O			→	←				G				→
12	1·23	1·083	←		M	→	←			O		→	←					G				→
11	1·39	1·107	←		M	→	←			O		→	←					G				→
10	1·55	1·131	←		M	→	←		O	→	←						G					→
9	1·77	1·163	←	M	→	←		O		→	←						G					→
8	2·00	1·195	←	M→	←			O		→	←						G					→
7	2·24	1·227	M	←			O			→	←						G					→
6	2·48	1·259	M	←			O			→	←						G					→
5	2·79	1·299	M	←			O			→	←						G					→
4	3·11	1·339	M	←			O			→	←						G					→
3	3·44	1·379	M	←			O			→	←						G					→
2	3·84	1·427	M	←			O			→	←						G					→
1	4·26	1·475	M	←			O			→	←						G					→

1-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: 1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
24	0·272	1·044																	M			
23	0·297	1·048																M				
22	0·348	1·056															M					
21	0·4	1·064														M						
20	0·45	1·072											M								O	
19	0·50	1·08								M								O				
18	0·61	1·096							M								O					
17	0·71	1·112							M								O					
16	0·82	1·128					M										O					
15	0·93	1·144					M									O						G
14	1·04	1·16				M								O								G
13	1·21	1·184				M								O							G	
12	1·39	1·208				M							O								G	
11	1·57	1·232				M							O								G	
10	1·75	1·256			M							O								G		
9	1·99	1·288		M							O									G		
8	2·24	1·32		M							O								G			
7	2·5	1·352		M							O								G			
6	2·77	1·384		M						O									G			
5	3·11	1·424		M						O									G			
4	3·46	1·464		M						O								G				
3	3·82	1·504		M						O								G				
2	4·26	1·552		M					O									G				
1	4·72	1·60		M					O									G				

$1\frac{1}{8}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: 1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
22	0·391	0·81													←				M			→
21	0·448	1·189												←			M			→	←	O →
20	0·51	1·197							←					M				→	←	O		→
19	0·56	1·205					←				M			→	←				O			→
18	0·68	1·221					←				M			→	←				O			→
17	0·80	1·237				←				M				→	←				O			→
16	0·92	1·253		←				M				→	←					O				→
15	1·04	1·269		←				M			→	←					O					→
14	1·17	1·285	←			M			→	←						O						→
13	1·35	1·309	←			M			→	←				O				→	←		G	→
12	1·55	1·333	←			M			→	←				O			→	←		G		→
11	1·74	1·357	←			M			→	←				O			→	←		G		→
10	1·94	1·381	←			M			→	←			O			→	←			G		→
9	2·21	1·413	←			M			→	←			O			→	←			G		→
8	2·49	1·445	←			M			→	←			O		→	←			G			→
7	2·77	1·477	←			M			→	←			O		→	←			G			→
6	3·06	1·509	←			M			→	←		O		→	←				G			→
5	3·43	1·549	←			M			→	←		O		→	←				G			→
4	3·81	1·589	←			M		→	←			O		→	←				G			→
3	4·2	1·629	←			M		→	←			O		→	←				G			→
2	4·68	1·677	←			M		→	←		O		→	←				G				→
1	5·17	1·725	←			M		→	←		O		→	←				G				→

$1\frac{1}{4}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: 1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
22	0·433	1·306														←			M			→
21	0·496	1·314														←			M			→
20	0·56	1·322													←		M		→	←	O	→
19	0·62	1·330										←				M			→	←	O	→
18	0·75	1·346								←				M				→	←		O	→
17	0·88	1·362						←				M			→	←			O			→
16	1·02	1·378			←					M					→	←			O			→
15	1·15	1·394			←					M					→	←			O			→
14	1·29	1·410													←				O			→
13	1·49	1·434												←				O				→
12	1·70	1·458											←				O			→	←	G →
11	1·92	1·482										←				O				→	←	G →
10	2·13	1·506										←				O			→	←	G	→
9	2·43	1·538										←			O			→	←		G	→
8	2·73	1·570										←			O		→	←		G		→
7	3·04	1·602										←			O		→	←		G		→
6	3·35	1·634										←		O		→	←			G		→
5	3·75	1·674								←			O			→	←			G		→
4	4·16	1·714								←			O		→	←			G			→
3	4·58	1·754							←			O			→	←			G			→
2	5·09	1·802							←			O		→	←				G			→
1	5·62	1·85							←			O		→	←				G			→

1⅜-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: 1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
22	0·475	1·431															←	- -	M	→
21	0·545	1·439													←	- -	- -	M	- -	→
20	0·61	1·447										←	- -	- -	M	- -	- -	→	←	O→
19	0·68	1·455								←	- -	- -	- -	M	- -	- -	- -	→	←	O→
18	0·83	1·471				←	- -	- -	- -	- -	M	- -	- -	- -	- -	→	←	- -	O	→
17	0·97	1·487		←	- -	- -	- -	- -	- -	M	- -	- -	- -	- -	- -	→	←	- -	O	→
16	1·11	1·503	←	- -	- -	- -	- -	M	- -	- -	- -	- -	→	←	- -	- -	O	- -	- -	→
15	1·26	1·519	←	- -	- -	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	→
14	1·41	1·535	←	- -	- -	- -	M	- -	- -	- -	→	←	- -	- -	- -	O	- -	- -	- -	→
13	1·63	1·559	←	- -	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	→
12	1·86	1·583	←	- -	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	→
11	2·09	1·607	←	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	- -	→
10	2·33	1·631	←	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	- -	→
9	2·65	1·663	←	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	- -	→
8	2·97	1·695	←	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	- -	→
7	3·3	1·727	←	- -	- -	M	- -	- -	→	←	- -	- -	- -	- -	O	- -	- -	- -	- -	→
6	3·64	1·759	←	- -	- -	M	- -	→	←	- -	- -	- -	- -	- -	O	- -	- -	- -	- -	→
5	4·07	1·799	←	- -	- -	M	- -	→	←	- -	- -	- -	- -	- -	O	- -	- -	- -	- -	→
4	4·51	1·839	←	- -	M	- -	→	←	- -	- -	- -	- -	- -	O	- -	- -	- -	- -	- -	→
3	4·96	1·879	←	- -	M	- -	→	←	- -	- -	- -	- -	- -	O	- -	- -	- -	- -	- -	→
2	5·51	1·927	←	- -	M	- -	→	←	- -	- -	- -	- -	- -	O	- -	- -	- -	- -	- -	→
1	6·08	1·975	←	- -	M	- -	→	←	- -	- -	- -	- -	- -	O	- -	- -	- -	- -	- -	→

1½-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
22	0·518	1·556															←		M	→
21	0·593	1·564													←			M		→
20	0·67	1·572											←				M			→
19	0·74	1·58										←				M			→	O
18	0·90	1·596									←			M			→	←	O	→
17	1·05	1·612								←				M			→	←	O	→
16	1·21	1·628							←			M			→	←		O		→
15	1·37	1·644						←				M			→	←		O		→
14	1·53	1·66					←				M				→	←		O		→
13	1·77	1·684				←					M				→	←		O		→
12	2·02	1·708				←				M				→	←			O		→
11	2·27	1·732				←				M			→	←			O			→
10	2·52	1·756				←			M			→	←				O			→
9	2·86	1·788				←			M		→	←				O				→
8	3·21	1·82				←			M		→	←				O				→
7	3·57	1·852				←			M		→	←				O				→
6	3·93	1·884				←		M		→	←					O				→
5	4·39	1·924				←		M		→	←					O				→
4	4·86	1·964				←		M	→	←					O					→
3	5·34	2·004				←		M	→	←					O					→
2	5·93	2·052				←	M	→	←						O					→
1	6·53	2·1				←	M	→	←						O					→

$1\frac{5}{8}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: $2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
20	0·72	1·697												← - -	- - -	M - -	- - →
19	0·81	1·705								← - -	- - -	- - -	- - -	M - -	- - -	- - -	- - →
18	0·97	1·721							← - -	- - -	- - -	- M -	- - -	- - -	- - →	← - -	O →
17	1·14	1·737						← - -	- - -	- - -	- - -	M - -	- - -	- - -	- - →	← - -	O →
16	1·31	1·753					← - -	- - -	- - -	- - -	M - -	- - -	- - -	- - →	← - -	- O -	- - →
15	1·48	1·769					← - -	- - -	- - -	- - -	M - -	- - -	- - -	- - →	← - -	- O -	- - →
14	1·65	1·785					← - -	- - -	- - -	- M -	- - -	- - -	- - →	← - -	- - -	O - -	- - →
13	1·91	1·809					← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- O -	- - -	- - →
12	2·17	1·833				← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	O - -	- - -	- - →
11	2·44	1·857				← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	O - -	- - -	- - →
10	2·71	1·881			← - -	- - -	- - -	- M -	- - -	- - -	- - →	← - -	- - -	- - -	O - -	- - -	- - →
9	3·08	1·913			← - -	- - -	- - -	- M -	- - -	- - -	- - →	← - -	- - -	- - -	O - -	- - -	- - →
8	3·45	1·945			← - -	- - -	- - -	- M -	- - -	- - -	- - →	← - -	- - -	- - -	O - -	- - -	- - →
7	3·83	1·977			← - -	- - -	- - -	- M -	- - -	- - -	- - →	← - -	- - -	- - -	O - -	- - -	- - →
6	4·22	2·009			← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	- O -	- - -	- - -	- - →
5	4·71	2·059			← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	- O -	- - -	- - -	- - →
4	5·21	2·089			← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	- O -	- - -	- - -	- - →
3	5·72	2·129			← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	- O -	- - -	- - -	- - →
2	6·35	2·177			← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	- O -	- - -	- - -	- - →
1	6·99	2·225			← - -	- - -	- - -	M - -	- - -	- - →	← - -	- - -	- - -	- O -	- - -	- - -	- - →

1¾-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches 2¼	2½	2¾	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
20	0·78	1·822											←		M		→
19	0·87	1·83										←			M		→
18	1·04	1·846									←		M			←	O →
17	1·22	1·862								←		M		→	←	O	→
16	1·4	1·878								←		M		→	←	O	→
15	1·59	1·894							←		M		→	←		O	→
14	1·77	1·91						←			M		→	←		O	→
13	2·05	1·934					←			M		→	←		O		→
12	2·33	1·958				←			M			→	←		O		→
11	2·62	1·982				←			M			→	←		O		→
10	2·91	2·006				←			M		→	←			O		→
9	3·3	2·038				←			M		→	←			O		→
8	3·7	2·07			←			M			→	←			O		→
7	4·1	2·102			←			M			→	←			O		→
6	4·51	2·134			←			M		→	←			O			→
5	5·03	2·174			←			M		→	←			O			→
4	5·56	2·214			←			M		→	←			O			→
3	6·1	2·254			←			M		→	←			O			→
2	6·76	2·302			←			M		→	←			O			→
1	7·44	2·35			←			M		→	←			O			→

$1\frac{7}{8}$-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	Radius in Inches: 3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	7	8	9
20	0·83	1·947									←		M	→
19	0·93	1·955								←		M		→
18	1·12	1·971							←			M		→
17	1·31	1·987						←			M			→
16	1·5	2·003					←		M		→	←	O	→
15	1·7	2·019					←		M		→	←	O	→
14	1·89	2·035				←		M		→	←		O	→
13	2·19	2·059				←		M		→	←		O	→
12	2·49	2·083			←		M		→	←		O		→
11	2·79	2·107			←		M		→	←		O		→
10	3·1	2·131		←		M		→	←			O		→
9	3·52	2·163	←			M		→	←			O		→
8	3·94	2·195	←			M		→	←			O		→
7	4·37	2·227	←			M		→	←			O		→
6	4·8	2·259	←		M		→	←			O			→
5	5·35	2·299	←		M		→	←			O			→
4	5·91	2·339	←		M		→	←			O			→
3	6·48	2·379	←		M		→	←			O			→
2	7·18	2·427	←		M		→	←			O			→
1	7·89	2·475	←		M		→	←			O			→

2-in. Bore Copper Tube

Gauge	Weight in lb. per ft.	O.D. in Inches	3	3¼	3½	3¾	4	4½	5	5½	6	7	8	9
			Radius in Inches											
20	0·89	2·072									←		M	→
19	0·99	2·08								←		M		→
18	1·19	2·096							←			M		→
17	1·39	2·112						←			M			→
16	1·6	2·128					←		M		→	←	O	→
15	1·8	2·144					←		M		→	←	O	→
14	2·01	2·16				←			M		→	←	O	→
13	2·33	2·184				←			M		→	←	O	→
12	2·65	2·208				←		M		→	←		O	→
11	2·97	2·232			←			M		→	←		O	→
10	3·29	2·256			←			M		→	←		O	→
9	3·72	2·288			←			M		→	←		O	→
8	4·18	2·32			←		M		→	←		O		→
7	4·63	2·352			←		M		→	←		O		→
6	5·09	2·384			←		M		→	←		O		→
5	5·67	2·424			←		M		→	←		O		→
4	6·26	2·464			←		M	→	←			O		→
3	6·86	2·504			←		M	→	←			O		→
2	7·6	2·552			←		M	→	←			O		→
1	8·35	2·6			←		M	→	←			O		→

Suitable Formers for Bending Standard Iron Pipes Cold to the Radii Shown

Nom. Bore	O.D.	Approx. Gauge	Radius in Inches 1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5½	6	6½	7	7½	8	8½	9
in. $\frac{1}{4}$	in. $\frac{17}{32}$	13	←											G											→
$\frac{3}{8}$	$\frac{11}{16}$	12	←	O →	←									G											→
$\frac{1}{2}$	$\frac{27}{32}$	11		←	O →	←									G										→
$\frac{3}{4}$	$1\frac{1}{16}$	10				←	O →	←								G									→
1	$1\frac{11}{32}$	9					←	O →	←							G									→
$1\frac{1}{4}$	$1\frac{11}{16}$	8								←	O →	←						G							→
$1\frac{1}{2}$	$1\frac{29}{32}$	7									←	O →	←					G							→
2	$2\frac{3}{8}$	6													←	O →	←		G		→				

O = Split overlap former with backformer.
G = Semi-grooved former with grooved roller.

Tube Bending Allowances

Note.—As the neutral line on a bent tube is not central, owing to the stretch on the heel being greater than the compression in the throat, these tables are calculated by multiplying the diameter of bend by three instead of three and one-seventh.

180°	150°	135°	120°	90°	60°	45°	30°	20°	10°	5°	Angle / Rad. in.
3	2·5	2·25	2	1·5	1	0·75	0·5	0·333	0·167	0·083	1
3·75	3·125	2·813	2·5	1·875	1·25	0·938	0·625	0·417	0·208	0·104	1·25
4·5	3·75	3·375	3	2·25	1·5	1·125	0·75	0·5	0·25	0·125	1·5
5·25	4·375	3·938	3·5	2·625	1·75	1·313	0·875	0·583	0·292	0·147	1·75
6	5	4·5	4	3	2	1·5	1	0·667	0·333	0·166	2
6·75	5·625	5·063	4·5	3·375	2·25	1·688	1·125	0·75	0·375	0·188	2·25
7·5	6·25	5·625	5	3·75	2·5	1·875	1·25	0·833	0·417	0·208	2·5
8·25	6·875	6·188	5·5	4·125	2·75	2·063	1·375	0·917	0·458	0·229	2·75
9	7·5	6·75	6	4·5	3	2·25	1·5	1	0·5	0·25	3
9·75	8·125	7·313	6·5	4·875	3·25	2·438	1·625	1·083	0·541	0·27	3·25
10·5	8·75	7·875	7	5·25	3·5	2·625	1·75	1·167	0·583	0·291	3·5
11·25	9·375	8·438	7·5	5·625	3·75	2·813	1·875	1·25	0·625	0·313	3·75
12	10	9	8	6	4	3	2	1·333	0·666	0·333	4
12·75	10·625	9·563	8·5	6·375	4·25	3·188	2·125	1·417	0·708	0·354	4·25
13·5	11·25	10·125	9	6·75	4·5	3·375	2·25	1·5	0·75	0·375	4·5
14·25	11·875	10·688	9·5	7·125	4·75	3·563	2·375	1·583	0·791	0·396	4·75
15	12·5	11·25	10	7·5	5	3·75	2·5	1·666	0·833	0·416	5
15·75	13·125	11·813	10·5	7·875	5·25	3·938	2·625	1·75	0·875	0·438	5·25
16·5	13·75	12·375	11	8·25	5·5	4·125	2·75	1·833	0·916	0·458	5·5
17·25	14·375	12·938	11·5	8·625	5·75	4·313	2·875	1·917	0·958	0·479	5·75
18	15	13·5	12	9	6	4·5	3	2	1	0·5	6
18·75	15·625	14·063	12·5	9·375	6·25	4·688	3·125	2·083	1·041	0·52	6·25
19·5	16·25	14·625	13	9·75	6·5	4·875	3·25	2·166	1·083	0·541	6·5
20·25	16·875	15·188	13·5	10·125	6·75	5·063	3·375	2·25	1·125	0·563	6·75
21	17·5	15·75	14	10·5	7	5·25	3·5	2·333	1·167	0·583	7
21·75	18·125	16·313	14·5	10·875	7·25	5·438	3·625	2·417	1·208	0·604	7·25
22·5	18·75	16·875	15	11·25	7·5	5·625	3·75	2·5	1·25	0·625	7·5
23·25	19·375	17·438	15·5	11·625	7·75	5·813	3·875	2·583	1·291	0·645	7·75
24	20	18	16	12	8	6	4	2·666	1·333	0·666	8
24·75	20·625	18·563	16·5	12·375	8·25	6·188	4·125	2·75	1·375	0·687	8·25
25·5	21·25	19·125	17	12·75	8·5	6·375	4·25	2·833	1·416	0·708	8·5
26·25	21·875	19·688	17·5	13·125	8·75	6·563	4·375	2·917	1·458	0·729	8·75
27	22·5	20·25	18	13·5	9	6·75	4·5	3	1·5	0·75	9
27·75	23·125	20·813	18·5	13·875	9·25	6·938	4·625	3·083	1·541	0·77	9·25
28·5	23·75	21·375	19	14·25	9·5	7·125	4·75	3·166	1·583	0·791	9·5
29·25	24·375	21·938	19·5	14·625	9·75	7·313	4·875	3·25	1·625	0·813	9·75
30	25	22·5	20	15	10	7·5	5	3·333	1·666	0·833	10

WIRE GAUGE STANDARDS

There are several wire gauge standards in use in this country, in America, and on the Continent. In this country we chiefly use the Standard Wire Gauge (S.W.G.), sometimes referred to as the British Imperial Wire Gauge, Birmingham Gauge (B.G.), also known as Stub's Iron Wire Gauge, and Stub's Steel Wire Gauge. It is important to remember the difference between Stub's Iron Wire Gauge and Stub's Steel Wire Gauge. The former, which, as stated, is also known as the Birmingham Gauge, is used to designate Stub's Soft-Wire Sizes, whilst Stub's Steel Wire Gauge is the one employed in measuring drawn steel wire or drill rod of Stub's make. It is also used by some makers of American drill rods. The Birmingham Wire Gauge must not be confused with the Birmingham Gauge.

Cast-steel drill rods or silver-steel rods in carbon, high-speed steel, or special alloys, are usually sold in this country by the Lancashire Pinion Gauge Sizes (letters and numbers). These, of course, do not coincide with the Imperial Standard Wire Gauge (S.W.G.), and when ordering rods of the type mentioned it is always necessary to state the gauge required—that is, whether L.P.G. or S.W.G.

A better system is to order the rods according to the diameter in decimals of an inch or millimetres. If no particular gauge is mentioned when ordering, the rods are sent according to Lancashire Pinion Wire Gauge (L.P.G.). Such rods are obtainable in 13-inch lengths (the French foot), 3 feet, 6 feet, and 1- and 2-metre lengths, but any length up to 24 feet can be supplied.

In America there is the American or Brown and Sharpe Gauge (B. & S.), Washburn and Moen, American Steel and Wire Co., and Roebling, and the U.S. Standard for steel and iron sheets and plates, whilst on the Continent gauge numbers refer to diameter in millimetres.

The suggestion has frequently been made that all wires, rods and sheets should be sold according to the decimal system of diameter or thickness, and one or two firms have adopted such a system. There seems no doubt that it will be generally adopted in a few years.

The Brown and Sharpe or American Wire Gauge (A.W.G.) is used in the United States to designate the diameter of uncoated brass, aluminium, phosphor bronze, zinc, German silver and copper wire, as well as for resistance wires and copper and aluminium insulated wires. The Washburn and Moen Gauge, which is variously known as the American Steel and Wire Co., the National Wire Gauge, the Roebling, and the Steel Wire Gauge, designates the diameter of bare annealed steel, iron and galvanized-iron wires, as well as for spring steel wire, but not for bare copper telephone wire. Music wire is sold according to the American Steel and Wire Co.'s music wire gauge.

Stub's or Birmingham Wire Gauge is chiefly used for iron and steel telephone and telegraph wires in this country, but in the United States they conform to the British Imperial Standard Wire Gauge (S.W.G.). The latter became a legal standard in England in 1883. The American Wire Gauge or the Brown and Sharpe Wire Gauge is employed in America for non-ferrous metal rods, but Stub's Steel Wire Gauge is employed for drill rods and wires, and tool steels. Twist drills and steel drill rods are sold according to their own gauges.

In some parts of this country Whitworth's Wire Gauge is sometimes used.

WIRE GAUGES

Abbreviations.—The following abbreviations are recognised through the trade as being standard and should, therefore, be used when ordering or specifying :—

A.W.G. : American Wire Gauge (B. & S. Gauge).
B/D or Brd. : Braided.
B.G. : Birmingham Gauge.
B. & S. : Brown & Sharpe's Gauge (A.W.G.).
D.C.C. : Double-cotton Covered.

D.L.R. : Double Lapping of Rubber.
D.P.R. : Double Lapping of Rubber.
D.P.C. : Double-paper Covered.
D.S.C. : Double-silk Covered.
Compd. Strand : Compressed Strand.
D.W.S. : Double White Silk.
Enam. : Enamelled.
Enam. & S.S.C. : Enamelled and Single-silk Covered.
Enam. & D.S.C. : Enamelled and Double-silk Covered.
Enam. & S.C.C. : Enamelled and Single-cotton Covered.
Enam. & D.C.C. : Enamelled and Double-cotton Covered.
H.C. : High Conductivity.
H.D. : Hard Drawn.
Lam. : Laminated.
Ord. : Ordinary Covering.
Pfd. : Paraffined.
Pl.Co. : Plain Copper.
S.C.C. : Single-cotton Covered.
S.D. : Soft Drawn.
S.I.R. or S.P.R. : Single Lapping of Pure Rubber.
Spec. or Spec. Fine : Specially Fine Covering.
S.P.C. : Single-paper Covered.
S.W.G. : Standard Wire Gauge.
S.W.S. : Single White Silk.
T.C.C. : Triple-cotton Covered.
T/d Cu. : Tinned Copper.
T.P.C. : Triple-paper Covered.
V.C. Tape : Varnished Cambric Tape (also known as "Empire" or "Lino" Tape).

Stub's Steel Wire Gauge

No. of Wire Gauge	*Diameter*	*No. of Wire Gauge*	*Diameter*	*No. of Wire Gauge*	*Diameter*	*No. of Wire Gauge*	*Diameter*
0000000	—	16	0·175	38	0·101	60	0·039
000000	—	17	0·172	39	0·099	61	0·038
00000	—	18	0·168	40	0·097	62	0·037
0000	—	19	0·164	41	0·095	63	0·036
000	—	20	0·161	42	0·092	64	0·035
00	—	21	0·157	43	0·088	65	0·033
0	—	22	0·155	44	0·085	66	0·032
1	0·227	23	0·153	45	0·081	67	0·031
2	0·219	24	0·151	46	0·079	68	0·030
3	0·212	25	0·148	47	0·077	69	0·029
4	0·207	26	0·146	48	0·075	70	0·027
5	0·204	27	0·143	49	0·072	71	0·026
6	0·201	28	0·139	50	0·069	72	0·024
7	0·199	29	0·134	51	0·066	73	0·023
8	0·197	30	0·127	52	0·063	74	0·022
9	0·194	31	0·120	53	0·058	75	0·020
10	0·191	32	0·115	54	0·055	76	0·018
11	0·188	33	0·112	55	0·050	77	0·016
12	0·185	34	0·110	56	0·045	78	0·015
13	0·182	35	0·108	57	0·042	79	0·014
14	0·180	36	0·106	58	0·041	80	0·013
15	0·178	37	0·103	59	0·040		

LANCASHIRE PINION GAUGE SIZES

Fraction of an In.	*Decimal of an In.*	*m/m Sizes*	*Approx. Feet in 1 lb.*	*Fraction of an In.*	*Decimal of an In.*	*m/m Sizes*	*Approx. Feet in 1 lb.*
$1\frac{1}{4}$	1·250	31·749	0·24	$\frac{29}{64}$	0·4531	11·508	1·83
$1\frac{15}{64}$	1·2344	31·353	0·246	D 1	0·451	11·455	1·92
$1\frac{7}{32}$	1·2187	30·953	0·252	C 1	0·443	11·252	2·04
$1\frac{13}{64}$	1·203	30·557	0·259	$\frac{7}{16}$	0·4375	11·112	2·05
$1\frac{3}{16}$	1·1875	30·161	0·266	B 1	0·431	10·947	2·16
$1\frac{11}{64}$	1·1718	29·762	0·273	$\frac{27}{64}$	0·4218	10·713	2·17
$1\frac{5}{32}$	1·1562	29·366	0·28	A 1	0·420	10·667	2·18
$1\frac{9}{64}$	1·1406	28·970	0·288	Z	0·413	10·49	2·19
$1\frac{1}{8}$	1·125	28·574	0·296	$\frac{13}{32}$	0·4062	10·317	2·20
$1\frac{7}{64}$	1·1094	28·177	0·305	Y	0·404	10·261	2·26
$1\frac{3}{32}$	1·0937	27·781	0·314	X	0·397	10·083	2·36
$1\frac{5}{64}$	1·0781	27·382	0·323	$\frac{25}{64}$	0·3906	9·921	2·47
$1\frac{1}{16}$	1·0625	26·986	0·33	W	0·386	9·804	2·60
$1\frac{3}{64}$	1·0468	26·587	0·34	V	0·377	9·575	2·66
$1\frac{1}{32}$	1·0312	26·191	0·353	$\frac{3}{8}$	0·375	9·524	2·72
$1\frac{1}{64}$	1·0156	25·795	0·364	U	0·368	9·347	2·73
1	1·000	25·399	0·376	$\frac{23}{64}$	0·3593	9·126	2·74
$\frac{63}{64}$	0·9843	25·000	0·38	T	0·358	9·093	2·89
$\frac{31}{32}$	0·9687	24·604	0·40	S	0·348	8·839	3·06
$\frac{61}{64}$	0·953	24·217	0·41	$\frac{11}{32}$	0·3438	8·732	3·16
$\frac{15}{16}$	0·9375	23·812	0·43	R	0·339	8·61	3·30
$\frac{59}{64}$	0·9218	23·413	0·45	Q	0·332	8·432	3·40
$\frac{29}{32}$	0·9062	23·017	0·48	$\frac{21}{64}$	0·3281	8·333	3·45
$\frac{57}{64}$	0·8906	22·621	0·49	P	0·323	8·204	3·64
$\frac{7}{8}$	0·875	22·225	0·495	O	0·316	8·026	3·65
$\frac{55}{64}$	0·8593	21·825	0·51	$\frac{5}{16}$	0·3125	7·937	3·85
$\frac{27}{32}$	0·8437	21·429	0·525	N	0·302	7·67	4·07
$\frac{53}{64}$	0·828	21·033	0·54	$\frac{19}{64}$	0·2968	7·538	4·10
$\frac{13}{16}$	0·8125	20·637	0·57	M	0·295	7·492	4·33
$\frac{51}{64}$	0·7968	20·238	0·59	L	0·290	7·365	4·49
$\frac{25}{32}$	0·7812	19·842	0·62	$\frac{9}{32}$	0·2812	7·142	4·61
$\frac{49}{64}$	0·7656	19·445	0·64	K	0·281	7·137	4·77
$\frac{3}{4}$	0·750	19·049	0·66	J	0·277	7·035	4·95
$\frac{47}{64}$	0·7343	18·652	0·69	I	0·272	6·908	5·09
$\frac{23}{32}$	0·7187	18·262	0·72	H	0·266	6·756	5·41
$\frac{45}{64}$	0·703	17·858	0·75	$\frac{17}{64}$	0·2656	6·746	5·41
$\frac{11}{16}$	0·6875	17·462	0·80	G	0·261	6·629	5·47
$\frac{43}{64}$	0·6718	17·063	0·84	F	0·257	6·527	5·77
$\frac{21}{32}$	0·6562	16·667	0·86	E	0·250	6·35	6·11
$\frac{41}{64}$	0·6406	16·271	0·91	$\frac{1}{4}$	0·250	6·35	6·12
$\frac{5}{8}$	0·625	15·875	0·96	D	0·246	6·248	6·15
$\frac{39}{64}$	0·6093	15·475	1·00	C	0·242	6·146	6·50
$\frac{19}{32}$	0·5937	15·079	1·08	B	0·238	6·045	6·74
$\frac{37}{64}$	0·578	14·683	1·12	$\frac{15}{64}$	0·2344	5·954	6·75
$\frac{9}{16}$	0·5625	14·287	1·18	A	0·234	5·943	6·76
$\frac{35}{64}$	0·5468	13·888	1·28	1	0·227	5·765	7·16
$\frac{17}{32}$	0·5312	13·492	1·33	2	0·219	5·562	7·58
$\frac{33}{64}$	0·5156	13·095	1·41	$\frac{7}{32}$	0·2187	5·554	7·75
$\frac{1}{2}$	0·500	12·699	1·50	3	0·212	5·384	8·00
H 1	0·494	12·547	1·65	4	0·207	5·257	8·05
$\frac{31}{64}$	0·4843	12·306	1·67	5	0·204	5·181	9·17
G 1	0·484	12·293	1·69	$\frac{13}{64}$	0·2031	5·159	9·18
F 1	0·475	12·064	1·73	6	0·201	5·105	9·20
$\frac{15}{32}$	0·4687	11·904	1·75	7	0·199	5·054	9·75
E 1	0·462	11·734	1·82	8	0·197	5·003	9·80

LANCASHIRE PINION GAUGE SIZES—*continued*

Fraction of an In.	*Decimal of an In.*	*m/m Sizes*	*Approx. Feet in 1 lb.*	*Fraction of an In.*	*Decimal of an In.*	*m/m Sizes*	*Approx. Feet in 1 lb.*
9	0·194	4·927	10·19	44	0·085	2·158	53·00
10	0·191	4·851	10·83	45	0·081	2·057	59·00
11	0·188	4·775	10·84	46	0·079	2·006	59·66
$\frac{3}{16}$	0·1875	4·762	10·85	$\frac{5}{64}$	0·0781	1·981	63·92
12	0·185	4·700	10·86	47	0·077	1·955	64·00
13	0·182	4·622	11·91	48	0·075	1·904	66·00
14	0·180	4·571	11·92	49	0·072	1·828	74·75
15	0·178	4·521	11·93	50	0·069	1·752	79·00
16	0·175	4·445	12·00	51	0·066	1·675	86·58
17	0·172	4·368	13·00	52	0·063	1·600	90·16
$\frac{11}{64}$	0·1718	4·363	13·10	$\frac{1}{16}$	0·0625	1·587	95·33
18	0·168	4·267	13·25	53	0·058	1·472	112·66
19	0·164	4·165	13·25	54	0·055	1·396	123·5
20	0·161	4·089	14·00	55	0·050	1·270	139·00
21	0·157	3·987	15·00	$\frac{3}{64}$	0·0468	1·191	167·00
$\frac{5}{32}$	0·1562	3·967	15·10	56	0·045	1·142	173·00
22	0·155	3·936	15·16	57	0·042	1·066	214·00
23	0·153	3·886	16·25	58	0·041	1·041	229·00
24	0·151	3·835	16·25	59	0·040	1·000	251·00
25	0·148	3·759	17·33	60	0·039	1·000	255·00
26	0·146	3·708	18·41	61	0·038	0·9648	266·00
27	0·143	3·632	18·42	62	0·037	0·939	283·00
$\frac{9}{64}$	0·1406	3·571	18·43	63	0·036	0·914	294·00
28	0·139	3·53	19·5	64	0·035	0·888	325·00
29	0·134	3·403	22·00	65	0·033	0·837	364·00
30	0·127	3·225	24·00	66	0·032	0·812	398·00
$\frac{1}{8}$	0·125	3·175	24·50	$\frac{1}{32}$	0·0312	0·792	408·00
31	0·120	3·047	26·00	67	0·031	0·787	416·00
32	0·115	2·920	29·00	68	0·030	0·761	442·00
33	0·112	2·844	30·33	69	0·029	0·736	481·00
34	0·110	2·793	31·41	70	0·027	0·685	517·00
$\frac{7}{64}$	0·1094	2·778	31·41	71	0·026	0·660	549·00
35	0·108	2·743	32·5	72	0·024	0·609	656·00
36	0·106	2·692	33·58	73	0·023	0·580	695·00
37	0·103	2·616	35·5	74	0·022	0·560	764·00
38	0·101	2·565	36·83	75	0·020	0·510	918·00
39	0·099	2·514	39·00	76	0·018	0·455	1129·00
40	0·097	2·463	41·00	77	0·016	0·405	1410·00
41	0·095	2·412	43·5	$\frac{1}{64}$	0·0156	0·396	1476·00
$\frac{3}{32}$	0·0938	2·382	43·75	78	0·015	0·380	1601·00
42	0·092	2·336	45·00	79	0·014	0·355	1851·00
43	0·088	2·235	50·00	80	0·013	0·330	2177·00

MAINS TRANSFORMER DATA

By means of a constant obtained from the table (right) the turns of wire for a primary of a transformer may easily be ascertained. For example, the constant of a transformer for a supply of 220 volts 50 cycles is 1760. Therefore, with a core of 1 sq. in. cross-sectional area you use 1760 turns of wire for primary. For a core of 2 sq. in. you use $\frac{1760}{2} = 880$ turns and so on. The secondary is directionally proportional to the voltage ratio.

Reactive Voltage	*Frequency Cycles per Second*								
	20	30	40	50	60	70	80	90	100
50	525	485	444	400	362	325	287	250	206
100	1050	975	888	800	725	650	575	500	412
110	1155	1073	976	880	797	715	632	550	453
150	1575	1455	1332	1200	1086	975	861	750	618
200	2100	1950	1775	1600	1450	1300	1150	1000	825
210	2205	2048	1864	1680	1533	1365	1207	1050	866
220	2310	2146	1952	1760	1594	1430	1264	1100	906
230	2415	2243	2041	1840	1666	1495	1321	1150	947
240	2520	2341	2130	1920	1739	1560	1378	1200	988
250	2625	2425	2220	2000	1810	1625	1435	1250	1030

Birmingham or Stub's Iron Wire Gauge

No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter
0000000	—	9	0·148	24	0·022	39	—
000000	—	10	0·134	25	0·020	40	—
00000	0·500	11	0·120	26	0·018	41	—
0000	0·454	12	0·109	27	0·016	42	—
000	0·425	13	0·095	28	0·014	43	—
00	0·380	14	0·083	29	0·013	44	—
0	0·340	15	0·072	30	0·012	45	—
1	0·300	16	0·065	31	0·010	46	—
2	0·284	17	0·058	32	0·009	47	—
3	0·259	18	0·049	33	0·008	48	—
4	0·238	19	0·042	34	0·007	49	—
5	0·220	20	0·035	35	0·005	50	—
6	0·203	21	0·032	36	0·004		
7	0·180	22	0·028	37	—		
8	0·165	23	0·025	38	—		

Birmingham Gauge for Sheets and Hoops

No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter
0000000	0·6666	9	0·1398	24	0·0247	39	0·0043
000000	0·6250	10	0·1250	25	0·0220	40	0·0038
00000	0·5883	11	0·1113	26	0·0196	41	0·0034
0000	0·5416	12	0·0991	27	0·0174	42	0·0030
000	0·5000	13	0·0882	28	0·0156	43	0·0027
00	0·4452	14	0·0785	29	0·0139	44	0·0024
0	0·3964	15	0·0699	30	0·0123	45	0·0021
1	0·3532	16	0·0625	31	0·0110	46	0·0019
2	0·3147	17	0·0556	32	0·0098	47	0·0017
3	0·2804	18	0·0495	33	0·0087	48	0·0015
4	0·2500	19	0·0440	34	0·0077	49	0·0013
5	0·2225	20	0·0392	35	0·0069	50	0·0012
6	0·1981	21	0·0349	36	0·0061		
7	0·1764	22	0·0312	37	0·0054		
8	0·1570	23	0·0278	38	0·0048		

Birmingham Wire Gauge for Silver and Gold

No.	In.	No.	In.	No.	In.	No.	In.
1	0·004	10	0·024	19	0·064	28	0·120
2	0·005	11	0·029	20	0·067	29	0·124
3	0·008	12	0·034	21	0·072	30	0·126
4	0·010	13	0·036	22	0·074	31	0·133
5	0·012	14	0·041	23	0·077	32	0·143
6	0·013	15	0·047	24	0·082	33	0·145
7	0·015	16	0·051	25	0·095	34	0·148
8	0·016	17	0·057	26	0·103	35	0·158
9	0·019	18	0·061	27	0·113	36	0·167

British Standard Wire Gauge

No. of Wire Gauge	*Diameter*	*No. of Wire Gauge*	*Diameter*	*No. of Wire Gauge*	*Diameter*	*No. of Wire Gauge*	*Diameter*
0000000	0·5000	9	0·1440	24	0·0220	39	0·0052
000000	0·4640	10	0·1280	25	0·0200	40	0·0048
00000	0·4320	11	0·1160	26	0·0180	41	0·0044
0000	0·4000	12	0·1040	27	0·0164	42	0·0040
000	0·3720	13	0·0920	28	0·0148	43	0·0036
00	0·3480	14	0·0800	29	0·0136	44	0·0032
0	0·3240	15	0·0720	30	0·0124	45	0·0028
1	0·3000	16	0·0640	31	0·0116	46	0·0024
2	0·2760	17	0·0560	32	0·0108	47	0·0020
3	0·2520	18	0·0480	33	0·0100	48	0·0016
4	0·2320	19	0·0400	34	0·0092	49	0·0012
5	0·2120	20	0·0360	35	0·0084	50	0·0010
6	0·1920	21	0·0320	36	0·0076		
7	0·1760	22	0·0280	37	0·0068		
8	0·1600	23	0·0240	38	0·0060		

Warrington Wire Gauge

Mark No.	*Size In.*	*Mark No.*	*Size In.*	*Mark No.*	*Size In.*	*Mark No.*	*Size In.*
7/0	$\frac{1}{2}$	2	0·274	10	0·133	17	0·053
6/0	$\frac{15}{32}$	3	0·25 or $\frac{1}{4}$	$10\frac{1}{2}$	0·125 or $\frac{1}{8}$	18	0·047
5/0	$\frac{7}{16}$	4	0·229	11	0·117	19	0·041
4/0	$\frac{13}{32}$	5	0·209	12	0·10 or $\frac{1}{10}$	20	0·036
3/0	$\frac{3}{8}$	6	0·191	13	0·090	21	0·0315 or $\frac{1}{32}$
2/0	$\frac{11}{32}$	7	0·174	14	0·079	22	0·028
0	0·326	8	0·159	15	0·069		
1	0·300	9	0·146	16	0·0625 or $\frac{1}{16}$		

Instrument-wire Gauge

No. (S.W.G.)	*Diameter In.*	*No. (S.W.G.)*	*Diameter In.*	*No. (S.W.G.)*	*Diameter In.*	*No. (S.W.G.)*	*Diameter In.*
4/0	0·400	11	0·116	25	0·020	39	0·0052
3/0	0·372	12	0·104	26	0·018	40	0·0048
2/0	0·348	13	0·092	27	0·0164	41	0·0044
0	0·324	14	0·080	28	0·0148	42	0·0040
1	0·300	15	0·072	29	0·0136	43	0·0036
2	0·276	16	0·064	30	0·0124	44	0·0032
3	0·252	17	0·056	31	0·0116	45	0·0028
4	0·232	18	0·048	32	0·0108	46	0·0024
5	0·212	19	0·040	33	0·0100	47	0·0020
6	0·192	20	0·036	34	0·0092	48	0·0016
7	0·176	21	0·032	35	0·0084	49	0·0012
8	0·160	22	0·028	36	0·0076	50	0·0010
9	0·144	23	0·024	37	0·0068		
10	0·128	24	0·022	38	0·0060		

MILLIMETRIC EQUIVALENTS OF S.W.G., B.G., AND B. & S.

No.	*S.W.G.*		*B.G.*		*B. & S.*		*No.*	*S.W.G.*		*B.G.*		*B. & S.*	
	inch	*mm.*	*inch*	*mm.*	*inch*	*mm.*		*inch*	*mm.*	*inch*	*mm.*	*inch*	*mm.*
4/0	0·400	10·160	0·454	11·532	0·4600	11·684	24	0·022	0·559	0·022	0·559	0·0201	0·511
3/0	0·372	9·449	0·425	10·795	0·4096	10·404	25	0·020	0·508	0·020	0·508	0·0179	0·455
2/0	0·348	8·839	0·380	9·652	0·3648	9·266	26	0·018	0·457	0·018	0·457	0·0159	0·404
0	0·324	8·230	0·340	8·636	0·3249	8·252	27	0·0164	0·417	0·016	0·406	0·0142	0·361
1	0·300	7·620	0·300	7·620	0·2893	7·348	28	0·0148	0·376	0·014	0·356	0·0126	0·320
2	0·276	7·010	0·284	7·214	0·2576	6·543	29	0·0136	0·345	0·013	0·330	0·0113	0·287
3	0·252	6·401	0·259	6·579	0·2294	5·827	30	0·0124	0·315	0·012	0·305	0·0100	0·254
4	0·232	5·893	0·238	6·045	0·2043	5·189	31	0·0116	0·295	0·010	0·254	0·0089	0·226
5	0·212	5·385	0·220	5·588	0·1819	4·620	32	0·0108	0·274	0·009	0·229	0·0079	0·203
6	0·192	4·877	0·203	5·156	0·1620	4·115	33	0·0100	0·254	0·008	0·203	0·0071	0·180
7	0·176	4·470	0·180	4·572	0·1443	3·665	34	0·0092	0·234	0·007	0·178	0·0063	0·160
8	0·160	4·064	0·165	4·191	0·1285	3·264	35	0·0084	0·213	0·005	0·127	0·0056	0·142
9	0·144	3·658	0·148	3·759	0·1144	2·906	36	0·0076	0·193	0·004	0·102	0·0050	0·127
10	0·128	3·251	0·134	3·404	0·1019	2·588	37	0·0068	0·173	—	—	0·0045	0·114
11	0·116	2·946	0·120	3·048	0·0907	2·304	38	0·0060	0·152	—	—	0·0040	0·102
12	0·104	2·642	0·109	2·769	0·0808	2·052	39	0·0052	0·132	—	—	0·0035	0·090
13	0·092	2·337	0·095	2·413	0·0720	1·829	40	0·0048	0·122	—	—	0·0031	0·079
14	0·080	2·032	0·083	2·108	0·0641	1·628	41	0·0044	0·112	—	—	0·0028	0·071
15	0·072	1·829	0·072	1·829	0·0571	1·450	42	0·0040	0·102	—	—	0·0025	0·063
16	0·064	1·626	0·065	1·651	0·0508	1·290	43	0·0036	0·091	—	—	0·0022	0·056
17	0·056	1·422	0·058	1·473	0·0453	1·151	44	0·0032	0·081	—	—	0·0020	0·051
18	0·048	1·219	0·049	1·245	0·0403	1·024	45	0·0028	0·071	—	—	0·0018	0·046
19	0·040	1·016	0·042	1·067	0·0359	0·912	46	0·0024	0·061	—	—	—	—
20	0·036	0·914	0·035	0·889	0·0320	0·813	47	0·0020	0·051	—	—	—	—
21	0·032	0·813	0·032	0·813	0·0285	0·724	48	0·0016	0·041	—	—	—	—
22	0·028	0·711	0·028	0·711	0·0253	0·643	49	0·0012	0·030	—	—	—	—
23	0·024	0·610	0·025	0·635	0·0226	0·574	50	0·0010	0·025	—	—	—	—

ENGLISH MUSIC WIRE GAUGE

Music Wire Gauge No.	Decimal Diameter	Sectional Area	No. of Feet in 1 Lb.	Weight Lb. per 100 Feet	Music Wire Gauge No.	Decimal Diameter	Sectional Area	No. of Feet in 1 Lb.	Weight Lb. per 100 Feet
9/0	0·005	0·0000196	14,705	0·0069	19	0·042	0·0013854	208	0·48
8/0	0·0055	0·0000237	12,048	0·0083	20	0·044	0·0015205	188	0·53
7/0	0·006	0·0000283	10,204	0·0098	21	0·046	0·0016619	172	0·58
6/0	0·0065	0·0000332	8,697	0·0115	22	0·048	0·0018095	158	0·63
5/0	0·007	0·0000385	7,462	0·0134	23	0·051	0·0020428	140	0·71
4/0	0·0075	0·0000442	6,493	0·0154	24	0·055	0·0023758	121	0·82
3/0	0·008	0·0000503	5,714	0·0175	25	0·059	0·0027340	105	0·95
2/0	0·0085	0·0000567	5,263	0·019	26	0·063	0·0031173	92	1·08
1/0	0·009	0·0000636	4,545	0·022	27	0·067	0·0035257	81	1·23
1	0·010	0·0000785	3,700	0·027	28	0·071	0·0039592	72	1·38
2	0·011	0·0000950	3,033	0·033	29	0·074	0·0043009	66	1·5
3	0·012	0·0001131	2,560	0·039	30	0·078	0·0047784	60	1·66
4	0·013	0·0001327	2,170	0·046	31	0·082	0·0052810	54	1·84
5	0·014	0·0001539	1,886	0·053	32	0·086	0·0054106	49	2·02
6	0·016	0·0002011	1,428	0·070	33	0·090	0·0063617	45	2·22
7	0·018	0·0002545	1,136	0·088	34	0·094	0·0069398	41	2·42
8	0·020	0·0003142	917	0·109	35	0·098	0·0075430	38	2·63
9	0·022	0·0003801	757	0·132	36	0·102	0·0081710	35	2·85
10	0·024	0·0004524	636	0·157	37	0·106	0·0088250	32	3·07
11	0·026	0·0005309	540	0·185	38	0·112	0·0098520	29	3·43
12	0·028	0·0006158	467	0·214	39	0·118	0·0109359	26	3·81
13	0·030	0·0007069	406	0·246	40	0·125	0·0122718	23	4·28
14	0·032	0·0008042	357	0·28	41	0·132	0·0136848	21	4·77
15	0·034	0·0009079	322	0·31	42	0·139	0·0151747	18·5	5·29
16	0·036	0·0010179	285	0·35	43	0·146	0·0167415	17	5·84
17	0·038	0·0011341	256	0·39	44	0·153	0·0183854	16·6	6·41
18	0·040	0·0012566	232	0·43	45	0·160	0·0201062	14·2	7·01

TABLE OF SIZES AND APPROXIMATE LENGTH PER POUND OF BRUNTON CAST-STEEL MUSIC WIRE

Music Wire Gauge No.	*Diam. in Decimals of an In.*	*Diam. in mm.*	*No. of Feet in 1 Lb.*	*Music Wire Gauge No.*	*Diam. in Decimals of an In.*	*Diam. in mm.*	*No. of Feet in 1 Lb.*
0000000	0·003	0·076	39,000	20	0·044	1·117	200
000000	0·004	0·102	23,433	21	0·046	1·168	180
00000	0·005	0·127	14,997	22	0·048	1·218	165
0000	0·0065	0·165	8,620	23	0·051	1·294	150
000	0·007	0·177	7,652	24	0·055	1·396	130
00	0·0085	0·215	5,138	25	0·059	1·5	110
0	0·009	0·23	4,564	26	0·063	1·6	95
1	0·010	0·254	3,973	27	0·067	1·7	85
2	0·011	0·28	3,415	28	0·071	1·8	75
3	0·012	0·305	2,955	29	0·074	1·89	68
4	0·013	0·33	2,581	30	0·078	1·98	61
5	0·014	0·355	2,026	31	0·082	2·08	55
6	0·016	0·406	1,553	32	0·086	2·18	50
7	0·018	0·457	1,221	33	0·090	2·29	40
8	0·020	0·508	995	34	0·098	2·49	38
9	0·022	0·559	755	35	0·104	2·64	34
10	0·024	0·61	690	36	0·110	2·79	30
11	0·026	0·66	575	37	0·117	2·97	28
12	0·028	0·71	485	38	0·121	3·07	26
13	0·030	0·76	420	39	0·130	3·3	22
14	0·032	0·812	375	40	0·140	3·56	19
15	0·034	0·863	330	5/32	0·156	3·96	15
16	0·036	0·914	295	11/64	0·172	4·368	13
17	0·038	0·965	265	3/16	0·187	4·762	10·85
18	0·040	1·016	235	7/32	0·218	5·554	7·75
19	0·042	1·066	215	¼	0·250	6·35	6·12

AMERICAN OR B. & S. WIRE GAUGE

No. of Wire Gauge	*Diameter*	*No. of Wire Gauge*	*Diameter*	*No. of Wire Gauge*	*Diameter*	*No. of Wire Gauge*	*Diameter*
0000000	—	9	0·1144	24	0·0201	39	0·0035
000000	0·5800	10	0·1019	25	0·0179	40	0·0031
00000	0·5165	11	0·0907	26	0·0159	41	0·0028
0000	0·4600	12	0·0808	27	0·0142	42	0·0025
000	0·4096	13	0·0720	28	0·0126	43	0·0022
00	0·3648	14	0·0641	29	0·0113	44	0·0020
0	0·3429	15	0·0571	30	0·0100	45	0·00176
1	0·2893	16	0·0508	31	0·0089	46	0·00157
2	0·2576	17	0·0453	32	0·0080	47	0·00140
3	0·2294	18	0·0403	33	0·0071	48	0·00124
4	0·2043	19	0·0359	34	0·0063	49	0·00099
5	0·1819	20	0·0320	35	0·0056	50	0·00088
6	0·1620	21	0·0285	36	0·0050		
7	0·1433	22	0·0253	37	0·0045		
8	0·1285	23	0·0226	38	0·0040		

U.S. Standard for Steel and Iron Sheets and Plates

No. of Wire Gauge	*Thickness**	*No. of Wire Gauge*	*Thickness**	*No. of Wire Gauge*	*Thickness**	*No. of Wire Gauge*	*Thickness**
0000000	0·4900	9	0·1532	24	0·0245	39	0·0057
000000	0·4600	10	0·1379	25	0·0214	40	0·0054
00000	0·4290	11	0·1225	26	0·0184	41	0·0052
0000	0·3980	12	0·1072	27	0·0169	42	0·0050
000	0·3680	13	0·0919	28	0·0153	43	0·0048
00	0·3370	14	0·0766	29	0·0138	44	0·0046
0	0·3060	15	0·0689	30	0·0123	45	—
1	0·2757	16	0·0613	31	0·0107	46	—
2	0·2604	17	0·0551	32	0·0100	47	—
3	0·2451	18	0·0490	33	0·0092	48	—
4	0·2298	19	0·0429	34	0·0084	49	—
5	0·2145	20	0·0368	35	0·0077	50	—
6	0·1991	21	0·0337	36	0·0069		
7	0·1838	22	0·0306	37	0·0065		
8	0·1685	23	0·0276	38	0·0061		

* This is a "weight gauge," the actual standard being in ounces per square foot. The thicknesses equivalent to the standard weights as given in this columnn are based upon 0·2833 lb. per cubic inch and apply to steel and open-hearth iron.

Alhoff & Muller Music Wire Gauge

Gauge No.	*Diameter*	*Gauge No.*	*Diameter*	*Gauge No.*	*Diameter*	*Gauge No.*	*Diameter*
2/0	0·008	9	0·022	19	0·042	29	0·074
0	0·009	10	0·024	20	0·044	30	0·078
1	0·010	11	0·026	21	0·046	31	0·082
2	0·011	12	0·028	22	0·048	32	0·086
3	0·012	13	0·030	23	0·051	33	0·090
4	0·013	14	0·032	24	0·055	34	0·094
5	0·014	15	0·034	25	0·059	35	0·098
6	0·016	16	0·036	26	0·063	36	0·102
7	0·018	17	0·038	27	0·067		
8	0·020	18	0·040	28	0·071		

Felten & Guilleaume Music Wire Gauge

Gauge No.	*Diameter*	*Gauge No.*	*Diameter*	*Gauge No.*	*Diameter*	*Gauge No.*	*Diameter*
4/0	0·0068	6	0·0157	15	0·0342	24	0·0550
3/0	0·0075	7	0·0177	16	0·0362	25	0·0590
2/0	0·0087	8	0·0197	17	0·0382	26	0·0630
0	0·0093	9	0·0216	18	0·0400	27	0·0670
1	0·0098	10	0·0236	19	0·0420	28	0·0710
2	0·0106	11	0·0260	20	0·0440	29	0·0740
3	0·0114	12	0·0283	21	0·0460	30	0·0780
4	0·0122	13	0·0303	22	0·0480	31	0·0820
5	0·0138	14	0·0323	23	0·0510	32	0·0860

W. N. BRUNTON MUSIC WIRE GAUGE

Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter
2/0	0·0085	10	0·024	21	0·046	32	0·086
0	0·009	11	0·027	22	0·048	33	0·092
1	0·010	12	0·029	23	0·050	34	0·098
2	0·011	13	0·031	24	0·054	35	0·104
3	0·012	14	0·032	25	0·058	36	0·110
4	0·013	15	0·034	26	0·062	37	0·117
5	0·014	16	0·036	27	0·066	38	0·121
6	0·016	17	0·038	28	0·069	39	0·130
7	0·017	18	0·040	29	0·072	40	0·140
8	0·019	19	0·042	30	0·076		
9	0·022	20	0·044	31	0·080		

WASHBURN & MOEN, AMERICAN STEEL & WIRE CO., AND ROEBLING WIRE GAUGE

No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter	No. of Wire Gauge	Diameter
0000000	0·4900	9	0·1483	24	0·0230	39	0·0075
000000	0·4615	10	0·1350	25	0·0204	40	0·0070
00000	0·4305	11	0·1205	26	0·0181	41	0·0066
0000	0·3938	12	0·1055	27	0·0173	42	0·0062
000	0·3625	13	0·0915	28	0·0162	43	0·0060
00	0·3310	14	0·0800	29	0·0150	44	0·0058
0	0·3065	15	0·0720	30	0·0140	45	0·0055
1	0·2830	16	0·0625	31	0·0132	46	0·0052
2	0·2625	17	0·0540	32	0·0128	47	0·0050
3	0·2437	18	0·0475	33	0·0118	48	0·0048
4	0·2253	19	0·0410	34	0·0104	49	0·0046
5	0·2070	20	0·0348	35	0·0095	50	0·0044
6	0·1920	21	0·0317	36	0·0090		
7	0·1770	22	0·0286	37	0·0085		
8	0·1620	23	0·0258	38	0·0080		

POEHLMANN MUSIC WIRE GAUGE

Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter
4/0	0·006	6	0·016	15	0·035	24	0·055
3/0	0·007	7	0·018	16	0·037	25	0·059
2/0	0·008	8	0·020	17	0·039	26	0·063
0	0·009	9	0·022	18	0·041	27	0·067
1	0·010	10	0·024	19	0·043	28	0·071
2	0·011	11	0·026	20	0·045	29	0·075
3	0·012	12	0·029	21	0·047	30	0·080
4	0·013	13	0·031	22	0·049		
5	0·014	14	0·033	23	0·051		

Roebling & Trenton Iron Co. Music Wire Gauge

Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter
4/0	0·007	9	0·022	21	0·046	33	0·090
3/0	0·0075	10	0·024	22	0·048	34	0·095
2/0	0·0085	11	0·026	23	0·051	35	0·100
0	0·009	12	0·028	24	0·055	36	0·105
1	0·010	13	0·030	25	0·059	37	0·110
2	0·011	14	0·032	26	0·063	38	0·115
3	0·012	15	0·034	27	0·067	39	0·120
4	0·013	16	0·036	28	0·071	40	0·125
5	0·014	17	0·038	29	0·074	41	0·130
6	0·016	18	0·040	30	0·078		
7	0·018	19	0·042	31	0·082		
8	0·020	20	0·044	32	0·086		

American Steel and Wire Co. Music Wire Gauge

Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter
6/0	0·004	8	0·020	21	0·047	34	0·100
5/0	0·005	9	0·022	22	0·049	35	0·106
4/0	0·006	10	0·024	23	0·051	36	0·112
3/0	0·007	11	0·026	24	0·055	37	0·118
2/0	0·008	12	0·029	25	0·059	38	0·124
0	0·009	13	0·031	26	0·063	39	0·130
1	0·010	14	0·033	27	0·067	40	0·138
2	0·011	15	0·035	28	0·071	41	0·146
3	0·012	16	0·037	29	0·075	42	0·154
4	0·013	17	0·039	30	0·080	43	0·162
5	0·014	18	0·041	31	0·085	44	0·170
6	0·016	19	0·043	32	0·090	45	0·180
7	0·018	20	0·045	33	0·095		

American Screw and Wire Co. Music Wire Gauge

Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter
6/0	0·0095	5	0·0202	15	0·0345	25	0·0586
5/0	0·010	6	0·0215	16	0·036	26	0·0626
4/0	0·011	7	0·023	17	0·0377	27	0·0675
3/0	0·012	8	0·0243	18	0·0395	28	0·072
2/0	0·0133	9	0·0256	19	0·0414	28	0·072
0	0·0144	10	0·027	20	0·0434	29	0·076
1	0·0156	11	0·0284	21	0·046	30	0·080
2	0·0166	12	0·0296	22	0·0483	31	0·085
3	0·0178	13	0·0314	23	0·051	32	0·092
4	0·0188	14	0·0326	24	0·055		

Wright Wire Co. Music Wire Gauge

Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter	Gauge No.	Diameter
2/0	0·0085	8	0·020	17	0·038	26	0·063
0	0·009	9	0·022	18	0·0405	27	0·067
1	0·010	10	0·024	19	0·042	28	0·071
2	0·011	11	0·026	20	0·044	29	0·0745
3	0·012	12	0·028	21	0·046	30	0·078
4	0·013	13	0·0305	22	0·0485	31	0·082
5	0·014	14	0·0325	23	0·0505	32	0·086
6	0·016	15	0·034	24	0·0545	33	0·090
7	0·018	16	0·036	25	0·0585	34	0·096

Enamelled Copper Wire

The following Table gives the maximum overall diameters laid down in B.S.I. Specification No. 156 of 1932.

Size S.W.G.	Nominal Diameter of Bare Wire	Maximum Overall Diameter of Enamelled Wire	Size S.W.G.	Nominal Diameter of Bare Wire	Maximum Overall Diameter of Enamelled Wire
	Inch	*Inch*		*Inch*	*Inch*
10	0·128	0·134	28	0·0148	0·0164
11	0·116	0·122	29	0·0136	0·0151
12	0·104	0·110	30	0·0124	0·0138
—	0·100	0·106	31	0·0116	0·0129
13	0·092	0·0980	32	0·0108	0·0121
—	0·084	0·0895			
			33	0·0100	0·0112
14	0·080	0·0850	34	0·0092	0·0103
—	0·076	0·0805	35	0·0084	0·0095
15	0·072	0·0760	36	0·0076	0·0086
16	0·064	0·0675	37	0·0068	0·0078
17	0·056	0·0590			
			38	0·0060	0·0069
18	0·048	0·0508	39	0·0052	0·0061
19	0·040	0·0425	40	0·0048	0·0056
20	0·036	0·0384	41	0·0044	0·0052
21	0·032	0·0343	42	0·0040	0·0048
22	0·028	0·0302			
			43	0·0036	0·0044
23	0·024	0·0261	44	0·0032	0·0039
24	0·022	0·0240	45	0·0028	0·0035
25	0·020	0·0220	46	0·0024	0·0030
26	0·018	0·0198	47	0·0020	0·0026
27	0·0164	0·0181			

The reader is also referred to *Wire and Wire Gauges* in which all of the wire-gauge standards are given.

DECIMAL EQUIVALENTS OF WIRE AND DRILL GAUGE

Mm.	*Frac.*	*Gge.*	*D. Eq.*	*Mm.*	*Frac.*	*Gge.*	*D. Eq.*
		80	0·0135			52	0·0635
		79	0·0145	1·65			0·0650
	1/64		0·0156	1·7			0·0669
0·4			0·0157			51	0·0670
		78	0·0160	1·75			0·0689
0·45			0·0177			50	0·0700
		77	0·0180	1·8			0·0709
0·5			0·0197	1·85			0·0728
		76	0·0200			49	0·0730
		75	0·0210	1·9			0·0748
0·55			0·0216			48	0·0760
		74	0·0225	1·95			0·0768
0·6			0·0236		5/64		0·0781
		73	0·0240			47	0·0785
		72	0·0250	2·00			0·0787
0·65			0·0256	2·05			0·0807
		71	0·0260			46	0·0810
0·7			0·0275			45	0·0820
		70	0·0280	2·1			0·0827
		69	0·0292	2·15			0·0846
0·75			0·0295			44	0·0860
		68	0·0310	2·2			0·0866
	1/32		0·0312	2·25			0·0886
0·8			0·0315			43	0·0890
		67	0·0320	2·3			0·0905
		66	0·0330	2·35			0·0925
0·85			0·0335			42	0·0935
		65	0·0350		3/32		0·0937
0·9			0·0354	2·4			0·0945
		64	0·0360			41	0·0960
		63	0·0370	2·45			0·0965
0·95			0·0374			40	0·0980
		62	0·0380	2·5			0·0984
		61	0·0390			39	0·0995
1·00			0·0394	2·55			0·1004
		60	0·0400			38	0·1015
		59	0·0410	2·6			0·1024
1·05			0·0413			37	0·1040
		58	0·0420	2·65			0·1043
		57	0·0430	2·7			0·1063
1·10			0·0433			36	0·1065
1·15			0·0453	2·75			0·1083
		56	0·0465		7/64		0·1094
	3/64		0·0469			35	0·1100
1·2			0·0472	2·8			0·1102
1·25			0·0492			34	0·1110
1·3			0·0512	2·85			0·1122
		55	0·0520			33	0·1130
1·35			0·0531	2·9			0·1142
		54	0·0550			32	0·1160
1·4			0·0551	2·95			0·1161
1·45			0·0571	3·00			0·1181
1·5			0·0591			31	0·1200
		53	0·0595	3·05			0·1201
1·55			0·0610	3·1			0·1220
	1/16		0·0625	3·15			0·1240
1·6			0·0630		1/8		0·1250

DECIMAL EQUIVALENTS OF WIRE AND DRILL GAUGE—*continued*

Mm.	*Frac.*	*Gge.*	*D. Eq.*	*Mm.*	*Frac.*	*Gge.*	*D. Eq.*
3·2			0·1260	4·9			0·1929
3·25			0·1279			10	0·1935
		30	0·1285	4·95			0·1949
3·3			0·1299			9	0·1960
3·35			0·1319	5·00			0·1968
3·4			0·1339	5·05			0·1988
3·45			0·1358			8	0·1990
		29	0·1360	5·1			0·2008
3·5			0·1378			7	0·2010
3·55			0·1398	5·15			0·2027
		28	0·1405		13/64		0·2031
	9/64		0·1406			6	0·2040
3·6			0·1417	5·2			0·2047
3·65			0·1437			5	0·2055
		27	0·1440	5·25			0·2067
3·7			0·1457	5·3			0·2087
		26	0·1470			4	0·2090
3·75			0·1476	5·35			0·2106
		25	0·1495	5·4			0·2126
3·8			0·1496			3	0·2130
3·85			0·1516	5·45			0·2146
		24	0·1520	5·5			0·2165
3·9			0·1535	5·55			0·2185
		23	0·1540		7/32		0·2187
3·95			0·1555	5·6			0·2205
	5/32		0·1562			2	0·2210
		22	0·1570	5·65			0·2224
4·00			0·1575	5·7			0·2244
		21	0·1590	5·75			0·2264
4·05			0·1595			1	0·2280
		20	0·1610	5·8			0·2283
4·1			0·1614	5·85			0·2303
4·15			0·1634	5·9			0·2323
4·2			0·1653			A	0·2340
		19	0·1660	5·95			0·2343
4·25			0·1673		15/64		0·2344
4·3			0·1693	6·00			0·2362
		18	0·1695			B	0·2380
4·35			0·1713	6·05			0·2382
	11/64		0·1719	6·1			0·2402
		17	0·1730			C	0·2420
4·4			0·1732	6·15			0·2421
4·45			0·1752	6·2			0·2441
		16	0·1770			D	0·2460
4·5			0·1772	6·25			0·2461
4·55			0·1791	6·3			0·2480
		15	0·1800	6·35	1/4	E	0·2500
4·6			0·1811	6·4			0·2520
		14	0·1820	6·45			0·2539
4·65			0·1831	6·5			0·2559
4·7		13	0·1850			F	0·2570
4·75			0·1870	6·55			0·2579
	3/16		0·1875	6·6			0·2598
4·8			0·1890			G	0·2610
		12	0·1890	6·65			0·2618
4·85			0·1909	6·7			0·2638
		11	0·1910		17/64		0·2656

DECIMAL EQUIVALENTS OF WIRE AND DRILL GAUGE—*continued*

Mm.	*Frac.*	*Gge.*	*D. Eq.*
6·75			0·2657
		H	0·2660
6·8			0·2677
6·85			0·2697
6·9			0·2716
		I	0·2720
6·95			0·2736
7·00			0·2756
		J	0·2770
7·05			0·2775
7·1			0·2795
		K	0·2810
	9/32		0·2812
7·15			0·2815
7·2			0·2835
7·25			0·2854
7·3			0·2874
7·35			0·2894
		L	0·2900
7·4			0·2913
7·45			0·2933
		M	0·2950
7·5			0·2953
	19/64		0·2969
7·55			0·2972
7·6			0·2992
7·65			0·3012
		N	0·3020
7·7			0·3031
7·75			0·3051
7·8			0·3071
7·85			0·3090
7·9			0·3110
	5/16		0·3125
7·95			0·3130
8·00			0·3150
		O	0·3160
8·05			0·3169
8·1			0·3189
8·15			0·3209
8·2			0·3228
		P	0·3230
8·25			0·3248
8·3			0·3268
	21/64		0·3281
8·35			0·3287
8·4			0·3307
		Q	0·3320
8·45			0·3327
8·5			0·3346
8·55			0·3366
8 6			0·3386
		A	0·3390
8·65			0·3405
8·7			0·3425
	11/32		0·3437
8·75			0·3445
8·8			0·3465
		S	0·3480
8·85			0·3484
8·9			0·3504
8·95			0·3524
9·00			0·3543
9·05			0·3563
		T	0·3580
9·1			0·3583
	23/64		0·3594
9·15			0·3602
9·2			0·3622
9·25			0·3642
9·3			0·3661
		U	0·3680
9·35			0·3681
9·4			0·3701
9·45			0·3720
9·5			0·3740
	3/8		0·3750
9·55			0·3760
		V	0·3770
9·6			0·3779
9·65			0·3799
9·7			0·3819
9·75			0·3839
9·8			0·3858
		W	0·3860
9·85			0·3878
9·9			0·3898
	25/64		0·3906
9·95			0·3917
10·00			0·3937
10·05			0·3957
		X	0·3970
10·1			0·3976
10·15			0·3996
10·2			0·4016
10·25			0·4035
		Y	0·4040
10·3			0·4055
	13/32		0·4062
10·35			0·4075
10·4			0·4094
10·45			0·4114
		Z	0·4130
10·5			0·4134
10·6			0·4173
10·7			0·4213
	27/64		0·4219
10·75			0·4232
10·8			0·4252
10·9			0·4291
11·00			0·4331
11·1			0·4370
	7/16		0·4375
11·2			0·4409

Eureka Resistance Wire

Current necessary to maintain given temperature rise
Wire coiled in air with free radiation

Size S.W.G.	Diam. (Inch)	Mm.	Amperes for a Temperature Rise of 100° C.	200° C.	300° C.	Resistance per 1,000 Yards at 60° F. Ohms	Weight per 1,000 Yards (lb.)
8	0·160	4·06	33·0	52	58·5	33·5	233·5
9	0·144	3·65	26·0	43	50	41·3	189·0
10	0·128	3·25	22·8	36	41·5	52·3	149·2
11	0·116	2·94	19·0	30	35·5	63·7	122·8
12	0·104	2·64	16·8	24	29·5	79·3	98·6
13	0·092	2·33	12·7	20	24·2	101·3	77·1
14	0·080	2·03	9·5	15	19·5	133·9	58·4
15	0·072	1·82	7·4	12·6	16·8	165·3	47·3
16	0·064	1·62	6·0	10·4	14·3	209·4	37·4
17	0·056	1·42	5·3	8·8	11·3	273·3	28·6
18	0·048	1·21	4·3	7·0	9·1	371·8	21·0
19	0·040	1·01	3·7	5·5	6·8	535·6	14·6
20	0·036	0·91	3·0	4·7	5·9	661·3	11·8
21	0·032	0·81	2·8	4·0	5·0	837·2	9·35
22	0·028	0·71	2·2	3·2	4·1	1,093	7·15
23	0·024	0·60	1·8	2·6	3·3	1,487	5·24
24	0·022	0·55	1·5	2·3	2·8	1,770	4·41
25	0·020	0·50	1·25	2·0	2.5	2,142	3·64
26	0·018	0·45	1·00	1·7	2·1	2,645	2·96
27	0·0164	0·41	0·90	1·5	1·9	3,186	2·46
28	0·0148	0·37	0·76	1·4	1·6	3,914	2·00
29	0·0136	0·34	0·68	1·2	1·5	4,634	1·69
30	0·0124	0·31	0·59	1·0	1·3	5,575	1·40
31	0·0116	0·29	0·52	0·90	1·00	6,370	1·23
32	0·0108	0·27	0·47	0·81	0·95	7,350	1·06
33	0·0100	0·25	0·42	0·74	0·85	8,571	0·912
34	0·0092	0·23	0·37	0·64	0·75	10,128	0·771
35	0·0084	0·21	0·33	0·56	0·65	12,149	0·644
36	0·0076	0·19	0·28	0·48	0.57	14,840	0·526
37	0·0068	0·17	0·26	0·43	0·51	18,536	0·421
38	0·0060	0·15	0·19	0·31	0·40	23,808	0·328
39	0·0052	0·13	0·16	0·26	0·31	31,696	0·246
40	0·0048	0·12	0·15	0·24	0·28	37,184	0·210
41	0·0044	0·11	0·14	0·21	0·26	44,268	0·176
42	0·0040	0·10	0·13	0·18	0·23	53,564	0·146
43	0·0036	0·09	0·11	0·17	0·20	66,136	0·118
44	0·0032	0·08	0·10	0·14	0·17	83,664	0·093
45	0·0028	0·07	0·08	0·13	0·15	108,648	0·072
46	0·0024	0·06	0·07	0·10	0·12	148,764	0·053
47	0·0020	0·05	0·05	0·08	0·10	214,284	0·036

EUREKA RESISTANCE WIRE—*continued*

Size S.W.G.	*Diam. (In.)*	*Mm.*	*Amperes for a Temperature Rise of* 100° C.	200° C.	300° C.	*Resistance per 1,000 Yards at 60° F. Ohms*	*Weight per 1,000 Yards (lb.)*
48	0·0016	0·040	0·04	0·060	0·075	334,000	0·023
49	0·0012	0·030	0·03	0·045	0·055	595,000	0·013
50	0·0010	0·025	0·02	0·030	0·040	855,000	0·009

The resistance values given above are standard and are subject to the tolerances given in B.S.I. Specification No. 115 of 1924.

Approximate characteristics:

Temperature coefficient	— 0·00007 to 0·00004 per° C.
Specific resistance	48 microhmes per cm. cube.
Comparative resistance. Copper Unity ...	28.
Specific gravity	8·9.
Thermo E.M.F. against copper (20° to 200° C.)	0·05 millivolts per ° C.
Melting-point	1·250° C.
Tensile strength	40 tons per square inch.

FUSE WIRE TABLES

Figures are approximate and for commercial use only

Fusing Current in Amperes	*Diameter in Inches* *Copper*	*Aluminium*	*Tin*	*Allotin*	*Lead*
1	0·0020	0·0026	0·0076	0·0084	0·0084
2	0·0036	0·0040	0·0116	0·0136	0·0124
3	0·0044	0·0052	0·0148	0·018	0·0164
4	0·0052	0·0068	0·018	0·022	0·020
5	0·0060	0·0076	0·022	0·024	0·024
10	0·0100	0·0124	0·036	0·040	0·036
15	0·0124	0·0156	0·044	0·048	0·048
20	0·0156	0·0190	0·052	0·064	0·060
25	0·018	0·0220	0·064	0·072	0·072
30	0·020	0·024	0·072	0·080	0·078
35	0·023	0·028	0·076	0·092	0·084
40	0·024	0·030	0·084	0·096	0·096
45	0·026	0·032	0·092	0·104	0·104
50	0·028	0·036	0·096	0·116	0·108
60	0·032	0·040	0·110	0·128	0·124
70	0·036	0·044	0·122	0·144	0·136
80	0·040	0·048	0·134	0·160	0·150
90	0·044	0·052	0·144	0·168	0·162
100	0·048	0·056	0·152	0·180	0·174
120	0·052	0·064	0·176	0·202	0·196

Sheet Zinc Trade Gauge

No.	In.	No.	In.	No.	In.	No.	In.
1	0·00395	8	0·0149	15	0·0375	22	0·0768
2	0·00554	9	0·0177	16	0·0426	23	0·0843
3	0·0067	10	0·0196	17	0·0478	24	0·0915
4	0·0082	11	0·0228	18	0·0526	25	0·0980
5	0·0097	12	0·0260	19	0·0577	26	0·1052
6	0·0114	13	0·0292	20	0·0632		
7	0·0132	14	0·0323	21	0·0699		

No. 1 Nickel Chrome Resistance Wire

Current necessary to maintain given temperature rise
Wire held straight and horizontal in air with free radiation

Size S.W.G.	Diameter (Inch)	Mm.	*Resistance per 1,000 Yards (Ohms)*			*Amperes for a Temperature Rise of*			Weight per 1,000 Yards (lb.)
			100° C.	500° C.	1,000° C.	100° C.	500° C.	1,000° C.	
16	0·064	1·62	457	474	475	6·4	18·75	42·5	34·9
17	0·056	1·42	597	619	621	5·3	15·50	35·1	26·7
18	0·048	1·21	813	844	846	4·3	12·60	28·3	19·6
19	0·040	1·01	1,171	1,215	1,218	3·4	10·00	22·1	13·6
20	0·036	0·91	1,446	1,500	1,504	2·9	8.60	18·9	11·0
21	0·032	0·81	1,830	1,890	1,904	2·4	7·40	16·0	8·73
22	0·028	0·71	2,390	2,480	2,486	1·9	6·30	13·4	6·68
23	0·024	0·60	3,254	3,377	3,384	1·5	5·20	10·8	4·91
24	0·022	0·55	3,873	4,019	4,028	1·3	4·45	9·5	4·12
25	0·020	0·50	4,685	4,862	4,873	1·13	3·95	8·35	3·41
26	0·018	0·45	5,784	6,000	6,017	0·99	3·50	7·28	2·76
27	0·0164	0·41	6,970	7,233	7,251	0·90	3·14	6·45	2·29
28	0·0148	0·37	8,557	8,880	8,901	0·80	2·80	5·65	1·86
29	0·0136	0·34	10,134	10,516	10,541	0·75	2·55	5·06	1·57
30	0·0124	0·31	12,191	12,651	12,681	0·68	2·30	4·50	1·31
31	0·0116	0·29	13,931	14,345	14,490	0·64	2·15	4·15	1·147
32	0·0108	0·27	16,071	16,676	16,716	0·60	1·99	3·78	0·994
33	0·0100	0·25	18,745	19,452	19,498	0·56	1·84	3·44	0·852
34	0·0092	0·23	22,146	22,980	23,035	0·52	1·68	3·12	0·721
35	0·0084	0·21	26,565	27,566	27,632	0·48	1·51	2·78	0·601
36	0·0076	0·19	32,457	33,681	33,762	0·43	1·34	2·48	0·492
37	0·0068	0·17	40,536	42,063	42,165	0·39	1·19	2·19	0·394
38	0·0060	0·15	52,077	54,042	54,171	0·35	1·03	1·91	0·306
39	0·0052	0·13	69,315	71,928	72,102	0·32	0·90	1·63	0·230
40	0·0048	0·12	81,360	84,426	84,627	0·30	0·83	1·51	0·196
			Resistance per 1,000 Yards at 60° F. (Ohms)						
41	0·0044	0·111	90,600						0·1650
42	0·0040	0·101	116,100						0·1365
43	0·0036	0·091	143,400						0·1107
44	0·0032	0·081	153,000						0·0873
45	0·0028	0·071	237,000						0·0669
46	0·0024	0·061	322,800						0·0492
47	0·0020	0·050	464,700						0·0342
48	0·0016	0·040	690,000						0·0217
49	0·0012	0·030	1,251,000						0·0119
50	0·0010	0·025	1,858,800						0·0085

No. 2 Nickel Chrome Resistance Wire

Current necessary to maintain given temperature rise
Wire held straight and horizontal in air with free radiation

Size S.W.G.	Diameter (Inch)	Mm.	Resistance per 1,000 Yards (Ohms)			Amperes for a Temperature Rise of			Weight per 1,000 Yards (lb.)
			100° C.	500° C.	1,000° C.	100° C.	500° C.	1,000° C.	
16	0·064	1·62	475	511	528	6·6	19·3	42·1	34·6
17	0·056	1·42	621	668	690	5·4	16·3	35·0	26·4
18	0·048	1·21	844	909	939	4·2	13·1	27·8	19·4
19	0·040	1·01	1,216	1,310	1,353	3·2	10·0	20·95	13·5
20	0·036	0·91	1,500	1,617	1,670	2·7	8·6	17·80	10·9
21	0·032	0·81	1,901	2,047	2,114	2·18	6·75	14·05	8·64
22	0·028	0·71	2,483	2,673	2,761	1·92	5·72	11·83	6·62
23	0·024	0·60	3,380	3,639	3,759	1·66	4·81	9·73	4·86
24	0·022	0·55	4,023	4,332	4,474	1·52	4·37	8·74	4·08
25	0·020	0·50	4,866	5,240	5,412	1·39	3·93	7·75	3·37
26	0·018	0·45	6,006	6,470	6,682	1·23	2·50	6·67	2·73
27	0·0164	0·41	7,240	7,796	8,052	1·10	3·16	6·03	2·27
28	0·0148	0·37	8,888	9,570	9,885	0·01	2·83	5·30	1·84
29	0·0136	0·34	10,771	11,598	11,979	0·95	2·59	4·77	1·56
30	0·0124	0·31	12,662	13,635	14,083	0·88	2·32	4·26	1·29
31	0·0116	0·29	14,469	15,581	16,093	0·83	2·16	3·92	1·136
32	0·0108	0·27	16,691	17,974	18,564	0·78	2·00	3·59	0·985
33	0·0100	0·25	19,469	20,965	21,654	0·73	1·84	3·26	0·844
34	0·0092	0·23	23,001	24,768	25,582	0·67	1·68	2·95	0·715
35	0·0084	0·21	27,591	29,711	30,687	0·62	1.52	2·64	0·596
36	0·0076	0·19	33,711	36,300	37,494	0·57	1·27	2·36	0·487
37	0·0068	0·17	42,102	45,336	46,827	0·51	1·21	2·07	0·390
39	0·0060	0·15	54,096	58,245	60,159	0·47	1·06	1·77	0·304
39	0·0052	0·13	71,994	77,526	80,070	0·42	0·91	1·49	0·228
40	0·0048	0·12	84,501	90,993	93,984	0·40	0·84	1·38	1·194
			Resistance per 1,000 Yards at 60° F. (Ohms)						
41	0·0044	0·111	99,000						0·1632
42	0·0040	0·101	119,700						0·1353
43	0·0036	0·091	147,600						0·1095
44	0·0032	0·081	186,900						0·0864
45	0·0028	0·071	243,900						0·0663
46	0·0024	0·061	332,100						0·0486
47	0·0020	0·050	478,200						0·0339
48	0·0016	0·040	753,000						0·0214
49	0·0012	0·030	1,368,000						0·0118
50	0·0010	0·025	1,912,800						0·0084

WIRE ROPE

Haulage, Transmission and Standing Rope.—In haulage, transmission and standing rope construction, the 6 × 7 construction makes a relatively stiff rope capable of resisting external wear or abrasion. Large sheaves are necessary.

Seale Construction.—The next class, 6 × 12 construction, is more flexible, but not so flexible as 6 × 19. When made "Seale" construction, it is suited to but a limited number of uses. If made 6 × 12 or 6 × 19, the list is the same as 6 × 19 Regular rope, based on the grade of stock furnished.

Hoisting Rope.—In the 6 × 19 construction, universally known as hoisting rope, the wires are smaller than 6 × 7 and 6 × 12. This rope is less able to resist abrasion, but can be more readily bent round sheaves and drums.

Copper Wire Data

Standard Wire Gauge	Diameter in Inches	Resistance in Ohms per Yard	Resistance in Ohms per Pound	Pounds per Ohm	Weight in Pounds per 1,000 Yards	Yards per Pound	Turns per Inch				
							Enamel Covered	Single Silk Covered	Double Silk Covered	Single Cotton Covered	Double Cotton Covered
10	0·128	0·001868	0·0120	83·3	148·8	6·67		7·64	7·55	7·35	7·04
11	0·116	0·002275	0·0200	50·0	122·2	6·67		8·41	8·30	8·06	7·69
12	0·104	0·002831	0·0280	35·7	98·22	10·23		9·35	9·22	8·93	8·48
13	0·092	0·003617	0·0550	18·1	76·86	13·00		10·5	10·4	10·0	9·43
14	0·080	0·004784	0·0820	12·2	58·12	17·16		12·1	11·8	11·4	10·6
15	0·072	0·005904	0·1400	7·14	47·08	21·23		13·3	13·1	12·5	11·6
16	0·064	0·007478	0·2021	4·95	37·20	26·86	15·0	14·9	14·6	14·1	13·2
17	0·056	0·009762	0·3423	2·38	28·48	35·00	17·1	16·9	16·5	15·9	14·7
18	0·048	0·01328	0·6351	1·56	20·92	47·66	19·8	20·0	19·4	18·5	17·2
19	0·040	0·01913	1·315	0·757	14·53	68·66	23·7	23·8	23·0	21·7	20·0
20	0·036	0·02362	2·012	0·497	11·77	85·00	26·1	26·3	25·3	23·8	21·7
21	0·032	0·02990	3·221	0·309	9·299	107·6	29·4	29·4	28·2	26·3	23·8
22	0·028	0·03905	·498	0·181	7·120	140·6	33·3	33·3	31·8	29·4	26·3
23	0·024	0·05313	10·14	0·098	5·231	191·6	38·8	38·5	36·4	33·3	29·4
24	0·022	0·06324	14·38	0·069	4·395	228·3	42·1	42·1	40·0	35·7	31·3
25	0·020	0·07653	21·08	0·0471	3·632	275·3	46·0	46·0	43·5	38·5	33·3
26	0·018	0·09448	32·21	0·0309	2·942	340·0	50·6	50·6	47·6	41·7	35·7
27	0·0164	0·11138	46·35	0·0215	2·442	410·0	55·9	55·1	51·6	44·6	37·9
28	0·0148	0·1398	70·12	0·0141	1·980	503·0	61·4	60·4	56·2	48·1	40·2
29	0·0136	0·1655	98·65	0·0101	1·680	596·6	66·2	65·2	60·2	51·0	42·4
30	0·0124	0·1991	142·75	0·0069	1·396	716·6	73·3	72·0	67·1	54·4	44·7
31	0·0116	0·2275	185·80	0·0054	1·222	820·0	77·8	76·3	70·9	56·8	46·3
32	0·0108	0·2625	248·20	0·0040	1·059	943·3	83·0	81·3	75·2	63·3	50·5
33	0·0100	0·3061	337·50	0·0029	0·9081	1,100	88·9	87·0	80·0	66·7	52·6
34	0·0092	0·3617	471·00	0·0023	0·7686	1,300	98·0	93·4	85·5	70·4	54·9
35	0·0084	0·4338	676·50	0·0014	0·6408	1,556	106	101	91·8	80·6	61·0
36	0·0076	0·5300	1,009	0·00098	0·5254	1,903	116	110	102	86·2	64·1
37	0·0068	0·6620	1,574	0·00064	0·4199	2,380	128	120	110	92·6	67·6
38	0·0060	0·8503	2,598	0·000385	0·3269	3,056	143	133	121	100	71·4
39	0·0052	1·132	4,645	0·000217	0·2456	4,066	168	149	134	109	75·8
40	0·0048	1·328	6,360	0·000156	0·2092	4,766	180	159	142	144	78·1
41	0·0044	1·581	9,020	0·000112	0·1758	5,700	194	169	150		
42	0·0040	1·913	13,150	0·000076	0·1453	6,866	211	191	167		
43	0·0036	2·362	20,120	0·000050	0·1177	7,500	230	206	179		
44	0·0032	2·989	32,210	0·000030	0·0929	10,766	253	225	192		
45	0·0028	3·904	54,980	0·000015	0·0712	14,066	282	247	208		

Special Flexible Hoisting Rope.—In the special flexible hoisting rope, 6 × 37, the wires are still smaller than in 6 × 19, and the rope may be used over fairly small sheaves. This class of rope is not to be subjected to much external wear, particularly in the smaller sizes, as the wires will wear too quickly.

Extra-flexible Hoisting Rope.—In the extra-flexible hoisting rope, known as 8 × 19, it is more flexible than the 6 × 19, being composed of two additional strands, and can be used over smaller sheaves than 6 × 19. In flexibility it is about the same as 6 × 37, but not so strong owing to its larger hemp centre.

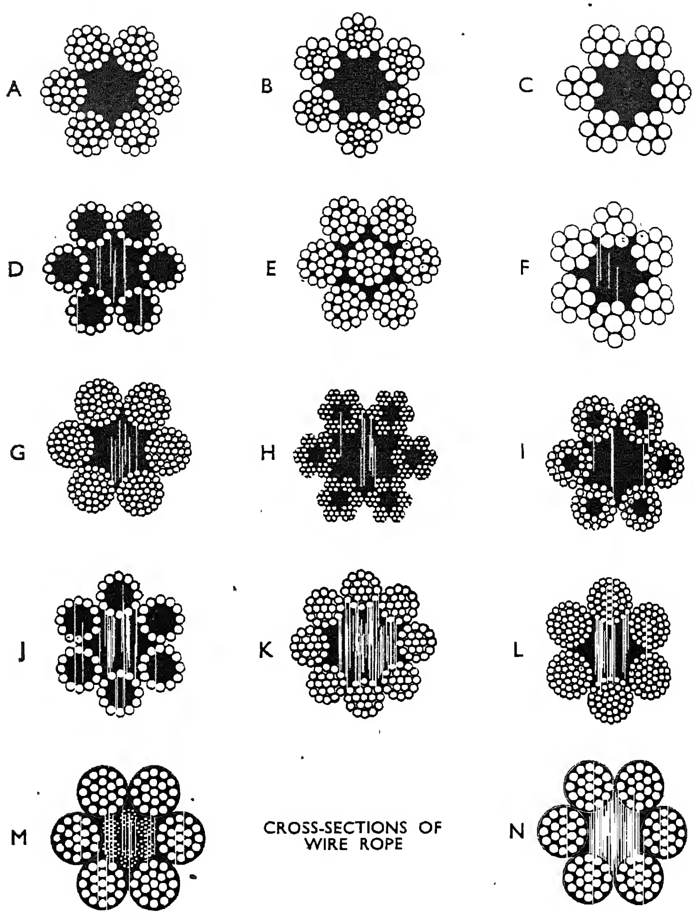
Running Ropes, Mooring Lines.—In 6 × 12 rope, known as running rigging construction and mooring lines, this is generally made galvanised. It has hemp core in each strand or seven hemp cores in the rope. This construction is more flexible than 6 × 19, but only about two-thirds as strong.

Tiller Rope.—Tiller rope construction is 6 ropes of 6 strands of 7 wires each. It is the most flexible rope made and can be bent around very small sheaves. Its construction is of very fine wires, hence will stand less surface wear than other types of ropes. The load should be light.

Non-Spinning Rope.—18 strands, 7 wires to the strand with a hemp centre. It is used principally as a hoisting rope and is non-rotating, i.e. non-spinning, and is made to overcome the spinning of loading buckets, beams or whatever may be hoisted.

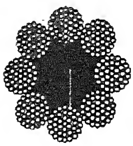
It is also used for bridge construction work or where single-line derricks are in use, also for crane elevator work, mine hoisting, etc.

Quarrymen and others, when hoisting by a single line, require two or more

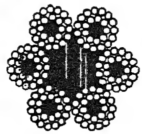


CROSS-SECTIONS OF WIRE ROPE

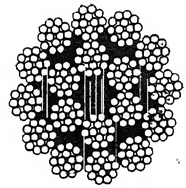
A, hoisting rope, 6 strands, each of 19 wires, laid about a hemp core ; **B,** cable construction Seale Lay, each strand of 19 wires, 9 outer wires, 9 small inner wires, and 1 large centre wire, the several strands laid about a hemp core; **C,** transmission or haulage rope, 6 strands, each of 7 wires, laid about a hemp core; **D,** galvanised compound running rope, 6 strands, each of 12 wires, laid about a hemp core; **E,** hoisting rope with wire core, 6 strands, each of 19 wires, laid about a wire strand of 19 wires; **F,** deep well-drilling cable, composed of 6 strands, 8 wires to the strand, with one hemp core; **G,** galvanised steel hawser, composed of 6 strands of 37 wires per strand, laid about a hemp core; **H,** tiller rope, composed of 6 independent wire ropes, laid about a hemp core; **I,** galvanised steel hawser and mooring line, composed of 6 strands of 24 wires per strand, laid about a hemp core with an additional hemp core in each strand; **J,** galvanised steel hawser and mooring line, 6 strands each composed of 12 wires with a hemp core and in turn laid about a hemp core; **K,** flexible hoisting rope, 8 strands, each of 19 wires, laid about a hemp core ; **L,** Extra-flexible hoisting rope, 6 strands each of 37 wires laid about a hemp rope ; **M,** armoured wire rope with wire centre; **N,** armoured wire rope with hemp centre.



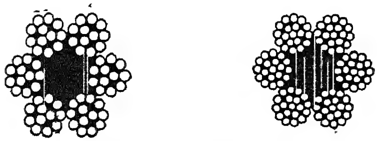
Crane rope.



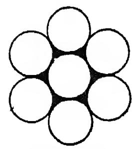
Crab rope.



Kilindo rope.



Coal-cutter haulage ropes.



Seven rods.

men with guide ropes to prevent blocks from revolving in their ascent. This rope overcomes the difficulty.

The principle of non-rotating rope is quite fully explained below. Improvement in this rope, i.e. non-spinning wire rope, according to invention, has for its object the production of wire rope which is non-rotating, of greater flexibility and wearing surface, and with more sectional area to stand a larger amount of wear and tear than wire rope of 6 strands of 19 wires.

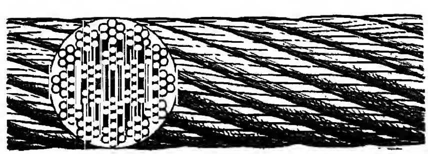
The object is accomplished by forming a wire rope of the inner rope, the outer casing constructed, arranged and twisted with the inner rope, to wit: the outer casing consists of a maximum number of strands, each having a stated number of wires of a stated area. The inner rope is composed of a stated number of strands, each having a stated number of wires. The interstices of the inner rope are wormed with lubricated hemp fibre, giving a cushion effect to the outer strands, and the inner rope strands respectively are by preference twisted in opposite directions, thus counterbalancing the outer strand wires. The rope is constructed of round wires, which are not subject to as much internal friction as flat or irregular-shaped core wires.

Galvanised Steel Hawsers and Mooring Lines.—Six strands of 12 wires to the strand with 7 hemp cores; 6 strands of 24 wires to the strand with 7 hemp cores; 6 strands of 37 wires to the strand with 1 hemp core.

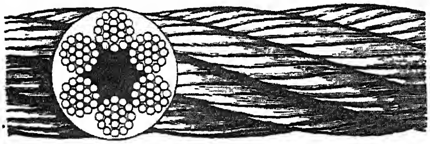
Galvanised mast arm or arc light rope.

Galvanised strand wire rope.

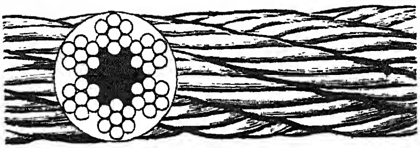
Sash cord.



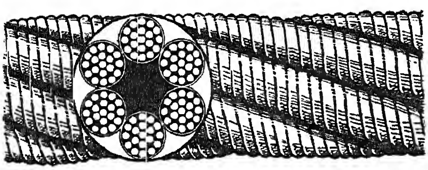
Non-spinning hoisting rope.



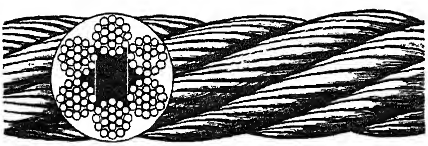
Armoured rope.



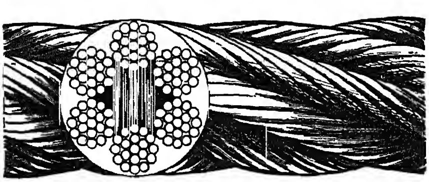
Regular lay.



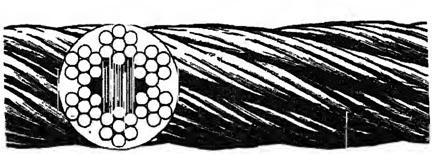
Lang lay.



Right lay.



Left lay.



Right and left lay.

Running Rope.—Galvanised iron and crucible steel, 6 strands of 12 wires to the strand with 7 hemp cores.

Galvanised Crucible Cast-steel Yacht Rigging or Guy Rope.—Six strands of 7 wires to the strand with 1 hemp core.

Flexible Galvanised Crucible Cast-steel Yacht Rope.—Six strands of 19 wires to the strand with 1 hemp core.

Galvanised Ship's Rigging or Guy Rope.—Seven or 12 wires to the strand with 1 hemp core.

Galvanised Strand.—Seven steel wires twisted into a single strand.

Armoured Wire Rope.—The tensile strength of wire rope of standard construction begins to decrease immediately it is put into service. This deterioration is frequently quite rapid, especially when the ropes are used on outdoor work where they are subjected to sudden changes in atmospheric conditions and to the abrasive action of gritty substances such as sand, pulverised rock, coal dust, etc.

In Waterbury Armoured Rope each strand of the rope is wound with flat steel wire having convex edges, and this forms a protective armour which relieves the tensile-strength wires of all abrasive wear and retains intact the strength of the rope until after these flat wires have been worn completely through.

The detail of Waterbury Armoured Rope construction which makes it a practical rope for hoisting and haulage is the convex edges of the armour wires. These convex edges permit the flexing of the rope without any creeping of the armour wires.

For severe usage in hoisting and haulage equipments, dredging, steam-shovel service and other general uses, it is far superior to the ordinary rope of bare wire construction.

Composed of 6 strands of 19 wires to the strand ; 6 strands of 37 wires to each strand, with hemp centre or wire centre as the conditions may demand, each strand being covered or wound with flat wires having convex edges. (Other constructions can be made to order.)

The object of flat wire serving is to take abrasion on crown of strands from the tensile-strength wires, also at the point the strand adjoins and wires converge and chafe during flexing movement.

The life of this rope is materially lengthened, this increase ranging from 50 to 150 per cent., according to conditions. The working life of the sheave grooves is maintained longer as the rope wearing to a smooth surface does not change the score of the sheaves or drums.

The flat wires when worn through do not project, but are pushed down into the interstices of the rope, thus giving a greater wearing surface than is ordinarily obtained.

Note that the flat wires are held transversely to the axis of the rope so that the same do not affect its flexibility.

The initial factor of safety is maintained longer in Waterbury Armoured Wire Rope (Gore Patent) than in any other construction. The strands are intended to take all the strains to which the rope is ordinarily subjected, and the flat wire covering is merely for the purpose of protecting the tensile-strength wires from abrasion and exposure and to assist the strands in retaining grease for internal lubrication.

An important factor is the lack of internal friction between the strands themselves, for in bending it is impossible for the flat wires to interlock, which is the failing of the ordinary construction.

Another advantage is that it is possible to use wire rope core, or in other words, a wire rope within a wire rope, as chafing between the inner rope and the outer or covering rope is absolutely prevented by the flat wires.

The flat wires are rolled from a special cold-drawn acid open-hearth round wire which leaves the edges convex and prevents the wire crowding during the bending of the rope.

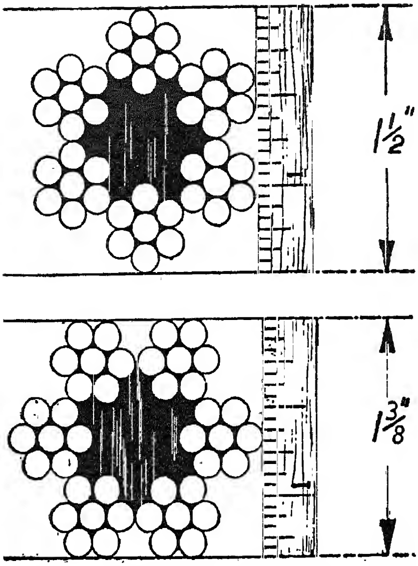
Lubricate ropes frequently. A suitable lubricant will add life to the rope, will prevent internal and external rust and will keep the rope pliable.

Fibreclad, Marline-covered Wire Rope.—Waterbury Fibreclad Wire Rope is a wire rope each strand of which is served with the best grade of tarred Russian hemp marline. This fibre covering prevents the chafing and wear of the wire strands during flexing movements, and after being in service a short time this fibre covering packs into the interstices of the strands, resulting in a rope having a smooth cylindrical surface.

The tarred marline covering also protects the wire strands of the rope from moisture or water, eliminating the possibility of rust and also preventing foreign matter such as coal or cement, dust, gases and fumes, etc., from working through to the wire strands. Unlike manila rope, Fibreclad is unaffected by changes in atmospheric conditions ; it will not stretch in dry weather nor contract in wet weather. Manila rope will swell and jam the blocks. Waterbury Fibreclad Rope will not swell, nor jam, nor ice up in freezing weather.

Fibreclad Transmission Rope.—For transmission of power in mills or where driving-ropes are used in coal-breakers, for coal washing or coal crushing, cement mills, cotton mills and numerous other places, Fibreclad Rope is superior to either bare wire or manila rope as it combines the advantages of both and has none of their disadvantages. This rope is also particularly desirable for hoisting and other general uses.

It will work admirably on either English or American systems ; sheaves need not be changed ; it is not affected by weather or moisture ; it will not rust as the marline covering affords perfect protection. The marline also retains a sufficient amount of lubrication to preserve the wires for a long period of time. Fibreclad has great flexibility and high efficiency, unlimited capacity and the maximum of strength. The coefficient of friction of Fibreclad is such that V-shaped grooves are not essential, although more lasting results follow when



The right (top sketch) and the wrong (bottom sketch) way to measure a wire rope. The diameter of a rope is that of a true circle enclosing the rope. If a rope is measured the wrong way, and a pulley wheel is ordered grooved to take the rope, the groove would be too small.

ample contact is allowed (without pinching) or when the grooves fit closely the curvature of the rope's cross-section.

Wire Rope Lays

The lays of wire rope are known as Regular and Lang lay.

Regular Lay.—In the Regular lay rope, the strands are twisted in one direction and the strands laid into rope in the opposite direction.

The Lang Lay.—In Lang lay rope the strands of the rope are twisted in the same direction.

Lang lay rope is more readily untwisted than Regular lay rope. It is more difficult to tuck the strands securely in the splice, but is especially adapted to resisting external wear and grit action. The use of Lang lay rope is generally confined to mining operations.

Ropes are made right-hand lay, also left-hand lay. Right-hand lay rope corresponds to a right-hand threaded screw of long pitch. The use of left-hand lay rope is limited principally to elevators and places where the tendency of left-hand lay rope to untwist in one direction is offset by the tendency of the right-hand lay rope to untwist in the opposite direction. In drilling cable operations the majority of oil-well drilling ropes are made left-hand lay.

There is also what is known as Right and Left lay rope, generally made of 6 strands of 19 wires to the strand, 3 strands being made Regular lay and 3 strands Lang lay. This rope is seldom called for.

Uses.—The range of application is broad. A few of the uses, however, may be found noted below.

Haulage rope for mines and docks.

Hoisting rope for elevators, coal hoists, ore hoists, conveyors, derricks, stump pullers, steam shovels, dredges, logging, ballast and unloaders.

Special Flexible 6 × 37 and Extra Flexible 8 × 19 used for cranes, counterweights, ammunition hoists and dredging operations in some instances.

Standard ropes are used for derricks, ship's rigging, etc., when made galvanised. When made extra galvanised in hoisting and running rope construction, they are used for mooring and messenger lines, cargo hoists, ship's rigging, etc.

Galvanised hawsers are made 6 × 12, 6 × 24 or 6 × 37 for mooring and towing.

Wire Patenting.—This is a method of heat-treating wires and rods to render them suitable for wire drawing. The steel is heated to allow the carbon to diffuse throughout the entire material, and then slowly cooled.

Splicing Wire Rope

The tools required will be a small marlinespike, nipping cutters, and either clamps or a small hemp rope sling with which to wrap around and untwist the rope. If a bench vice is accessible, it will be found very convenient for holding the rope.

In splicing rope, a certain length is used up in making the splice. An allowance of not less than 16 ft. for ½-in. rope, and proportionately longer for larger sizes, must be added to the length of your endless rope in ordering.

Having measured carefully the length the rope should be after splicing, and marked the points 6 and 6′, Fig. A, you unlay the strands from each end of the rope to 6 and 6′ and then :

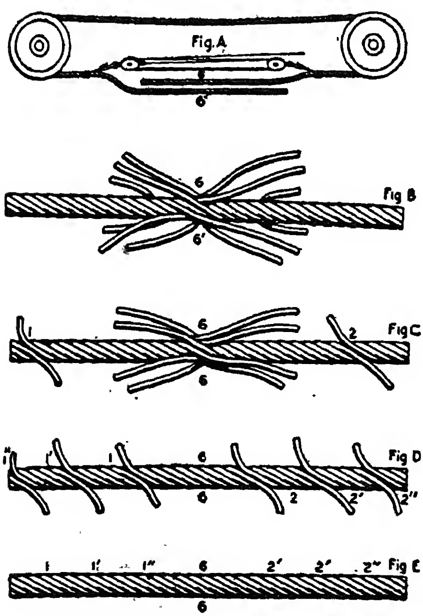
First : Interlock the six unlaid strands of each end alternately and draw them together so that the points 6 and 6′ meet as shown in Fig. B.

Second : Unlay a strand from one end and, following the unlay closely, lay into the seam or groove it opens the strand opposite it belonging to the other end of the rope until within a length equal to three or four times the length of one lay of the rope, and cut the other strand to about the same length from the point of meeting, as shown at 1, Fig. C.

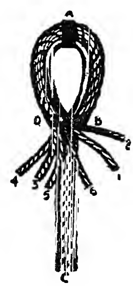
Third : Unlay the adjacent strand in the opposite direction and, following the unlay closely, lay in its place the corresponding opposite strand, cutting the ends, as described before, at 2, Fig. C.

It will be well after laying each pair of strands to tie them temporarily at the points 1 and 2.

Pursue the same course with the remaining four pairs of opposite strands,



The various stages in splicing a wire rope.



Method of splicing a thimble into a wire rope.

stopping each pair about eight or ten turns of the rope short of the preceding pair and cutting the ends as before.

You now have all the strands laid in their proper places, with their respective ends passing each other, as shown at D.

All methods of rope splicing are identical to this point: their variety consists in the method of tucking the ends. The one given below is that most generally practised.

It now remains to secure the ends.

Clamp the rope either in a vice at a point to the left of 1, Fig. D, and, by a hand clamp applied near 1, open up the rope by untwisting sufficiently to cut the hemp core at 1, and seizing it with the nippers, let your assistant draw it out slowly, you following it closely, crowding the strand in its place until it is all laid in. Cut the hemp core where the strands end and push the end back into its place. Remove the clamps and let the rope close together round it. Draw out the hemp core in the opposite direction, and lay the other strand in the centre of the rope in the same manner. Repeat the operation at the given remaining points, where the ends pass each other at, 1, 1, 2, 2, etc., with small wooden mallets, and the splice is complete, as shown in Fig. E.

If the clamp or vice is not obtainable, two rope slings and short wooden levers may be used to untwist and open up the rope.

A rope spliced as above will be nearly as strong as the original rope and smooth everywhere. After running a few days, the splice, if well made, cannot be pointed out except by close examination of an expert.

To Splice a Thimble into a Wire Rope of Six Strands.—Take your thimble and make it fast at A. Be sure to leave your rope long enough from A to the numbered ends for splicing, better a little too long than too short. For a $\frac{5}{8}$-in. or $\frac{3}{4}$-in. diameter rope take at least 2 ft. After you have made your thimble fast at A, bend your rope round it and clip it in a vice and suspend it from a beam by a rope attached at A; have C hanging down with a weight attached to it, which will help to keep it steady while splicing. Unlay the strands as far as the bands D B, and cut away the hemp core. Take your splicing knife and insert it below the band on the side D, and drive it through the centre of the rope, so as to have three strands on each side of your knife. Keep your knife there while you get No. 1 through above it. Before passing each end through, take a little of the twist out of the strand. It will lay better if you do. Then pull the strand up towards and as close as you can get it to the band B D. Take out the knife, insert again in the same place as before, but bring it out one strand to the left of the last, that is, have two strands on the left and four on the right side of the knife. You are working from side D, and when we speak of the left of the knife you will take it from your left. Put No. 2 through above the knife, and with the aid of a knife force this also as close and as tight as possible to the band. Insert your knife again at the same place as last, but only let there be one strand on the left and five on the right side of it. Take No. 3 through and force it also up towards the band. After this you will open one strand at a time, and bring Nos. 4, 5, and 6, in their turn, over and under a strand. If you have followed us rightly you will now have the six ends through, no two ends will be out, between the two strands each one will have its own place. You must now begin with No. 1, but do not this time take it through the middle of the rope, but serve it as you did the last three, that is, take it and the others in their turn over and under one strand only. Now split your strands and take half of each through again. File or break off the wires about $\frac{1}{4}$ in. from the face of the rope. Now hammer the splice into shape. If you wish to hide the ends of the broken wires you can cover with marline twine.

Factors of Safety

Most wire rope tables figure a factor of safety 5 to 1, but where the conditions are hoisting, they are increased from 7 to 10.

Great care should be exercised as regards size and quality of rope to meet stresses.

It might be noted that in a rope of given strength, one could use on hoisting rope, say, 1-inch crucible steel or a $\frac{7}{8}$-inch plough steel and get almost the same factor of safety. In a case where the sheaves must of necessity be small, $\frac{7}{8}$-inch plough steel 6 × 19 would probably be preferable to the 1-inch crucible steel 6 × 19. A safe rule to follow is to have the sheave diameter at least thirty times the diameter of the rope.

Iron, which enters into the making of wire rope, has a breaking strain of approximately 85,000 lb. per square inch, although the range is from 75,000 to 100,000 lb. per square inch.

In *Crucible Cast Steel* the tensile strength will run about 150,000 to 200,000 lb. per square inch of sectional area, depending upon the size of the finished wire.

Extra Crucible Cast Steel is a stronger grade of crucible open-hearth steel, and will run from 180,000 to 220,000 lb. per square inch of sectional area.

Plough Steel is a higher grade of open-hearth steel of a tensile strength running from 200,000 to 250,000 lb. per square inch of sectional area.

Improved Plough Steel will run from 220,000 to 280,000 lb. per square inch of sectional area. This is the toughest grade of material of high strength that has been produced, and will be found most satisfactory for hazardous operations. It must be borne in mind, however, that owing to the high tensile strength something is sacrificed for flexibility—larger sheaves are required than for the softer grades of stock.

Wire Rope Preservatives.—Wire ropes should be coated occasionally with some suitable material to preserve them from rust and corrosion. A good coat of boiled linseed oil will answer the purpose for ropes subjected only to atmospheric conditions. For haulage ropes, and especially such as have to run in wet places, we recommend some standard preparation of crude petroleum, or a mixture of this with graphite. The latter is specially applicable to shaft ropes, as it fills the interstices well and is not readily washed off. Materials containing acids should be avoided.

Compounds expressly prepared for coating wire ropes are offered by parties making a speciality of such materials.

Wire ropes should be examined frequently and a new one ordered before the old one is worn out. Attention to this will ensure safety and prevent accidents.

Wire ropes can be manufactured to any size or strength.

When wire rope is cut, a binder should be wrapped on each side of the place where the division is to be made, to prevent the rope from untwisting.

Wire Rope Installations.—The dimensions of the drum or pulley employed in any wire-rope installation are important factors in establishing the wire-rope size. If the drums or pulleys are too small, the wearing properties of the rope will be adversely affected, and there will also be a danger that the safety factor will be lowered by the breaking of individual wires as a result of excessive bending stresses.

As a guide, some average figures are given below, but it must be borne in mind that these figures themselves are subject to additional factors, e.g. speed, tensile strength of the wires used in the construction of the rope, and the design of the installations.

Winding ropes: Circumference × 33 minimum.
Haulage ropes: Circumference × 20 minimum.
Crane ropes, 6 × 19: Circumference × 7 minimum.
Crane ropes, 6 × 24: Circumference × 6 minimum.
Crane ropes, 6 × 27: Circumference × 6 minimum.
Crane ropes, 6 × 37: Circumference × 5 minimum.
Lifts and elevators, 6 × 12: Circumference × 10 minimum.
Lifts and elevators, 6 × 19 (9/9/1): Circumference × 13 minimum.
Lifts and elevators, 6 × 19: Circumference × 10 minimum.
Lifts and elevators, 6 × 24: Circumference × 8 minimum.

While smaller ratios than these are not recommended, no objection exists to the use of larger ratios, which should be advantageous to the rope.

Steel for Wire Ropes.—The wire ropes used in collieries, mines, suspension bridges, railways, cranes, hoists, lifts, and general engineering are usually made of carbon steel, but the carbon percentages vary. In general there are six distinct qualities, the first containing 0·5–0·15 per cent. carbon; the second 0·2–0·5 per cent.; the third 0·3–0·6 per cent.; the fourth 0·55–0·7 per cent.; the fifth, known as plough steel, has 0·65–0·8 per cent.; and the superior type has 0·7–0·85 per cent. carbon.

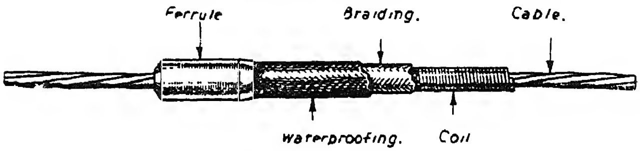
Round-strand wire ropes suitable for hauling and winding are made in the following sections: 6 × 6—5/1; 6 × 7—6/1; 6 × 12—9/3; 6 × 13—7/5/1; 6 × 15—8/6/1; 6 × 16—9/6/1; 6 × 17—10/6/1. The meaning of these dimensions is as follows: 6 × 6 means that there are six strands of six wires each; 5/1 means that the individual strands are themselves made up of 5 outer wires about one central wire; 10/6/1 means that in the individual strands there are ten wires about six wires about a central wire.

BOWDEN CABLES

Conduits and Corresponding Cables

(Conduits B52, B1 and B2 were formerly known as Bowden Nos. 52, 11 and 12 respectively.)
"Non-fray" cables do not untwist when cut and require no previous soldering. "Live Lay" cables must be soldered before cutting.

For All Sizes Above B3 Use "Bowdenex"



	Outer Conduit Dimensions						Cable Dimensions					
Size	External Diameter of Ferrule		Nominal Diameter Overall Conduit		Nominal Bore of Conduit		Type		Nominal Diameter		No. of Strands	Nominal Breaking Strain in Lb.
	in.	*mm.*	*in.*	*mm.*	*in.*	*mm.*	*Non-fray*	*Live*	*in.*	*mm.*		
B625	0·125	3·17	0·095	2·42	0·045	1·14	P7/62	7/62	0·020	0·508	7	45
B62	0·171	4·34	0·141	3·58	0·045	1·14	P7/62	7/62	0·020	0·508	7	45
B52	0·179	4·54	0·156	3·96	0·071	1·80	P7/62	7/62	0·020	0·508	7	45
B52	0·179	4·54	0·156	3·96	0·071	1·80	P7/51	7/51	0·036	0·915	7	180
B52	0·179	4·54	0·156	3·96	0·071	1·80	P19/52A	19/52A	0·045	1·14	19	325
B1H	0·218	5·53	0·195	5·07	0·093	2·38	P19/1	19/1	0·062	1·58	19	500
B1H	0·218	5·53	0·195	5·07	0·093	2·38	P19/2	19/2	0·075	1·91	19	750
B1	0·218	5·53	0·188	4·77	0·100	2·54	P19/52A	19/52A	0·045	1·14	19	325
B1	0·218	5·53	0·188	4·77	0·100	2·54	P19/1	19/1	0·062	1·58	19	500
B1	0·218	5·53	0·188	4·77	0·100	2·54	P19/2	19/2	0·075	1·91	19	750
B2H	0·243	6·18	0·212	5·38	0·109	2·77	P19/2A	19/2A	0·087	2·20	19	1,000
B2	0·243	6·18	0·212	5·38	0·125	3·18	P19/2A	19/2A	0·087	2·20	19	1,000
B2	0·243	6·18	0·212	5·38	0·125	3·18	P19/2B	19/2B	0·105	2·61	19	1,400
B2	0·243	6·18	0·212	5·38	0·125	3·18	P49/3L	—	0·111	2·86	49	1,000
B3H	0·265	6·75	0·237	6·02	0·136	3·45	P49/3L	—	0·111	2·86	49	1,000
B3H	0·265	6·75	0·237	6·02	0·136	3·45	P36/3	—	0·111	2·86	36	1,400
B3	0·265	6·75	0·237	6·02	0·154	3·92	P36/4	—	0·126	3·20	36	1,800
B3	0·265	6·75	0·237	6·02	0·154	3·92	P49/4L	—	0·126	3·20	48	1,625

Nomenclature.—Cables are described by number of individual wires *before* the oblique stroke and by size number following it. Thus 19/1 is constructed of

19 wires and is size No. 1. Prefix letter "P" denotes "Performed" (Non-fray) construction. Suffix letter "L" denotes Lang's Lay.

Non-Corrosive and Non-Magnetic Cables

A special series of these cables in "Tungum" Alloy have been developed to operate in Bowden Mechanisms.

Many of these cables are *not suitable for use as inner members* of Bowden Mechanisms.

STOCK SIZES

(With approximate particulars of size, weight, and breaking strain)

Diam. in In.	*Bowden Size*	*Weight in Lb. per 1,000 ft.*	*Breaking Strain in Lb.*	*Diam. in In.*	*Bowden Size*	*Weight in Lb. per 1,000 ft.*	*Breaking Strain in Lb.*
0·020	7/62	0·800	45	0·162	P36/5	53·50	2,600
0·036	7/51	2·780	180	0·162	49/5L	44·00	2,350
0·045	7/52	4·375	300	0·162	84/5	46·00	2,250
0·045	19/52A	4·750	325	0·187	P36/6	76·00	3,600
0·062	19/1	8·00	500	0·187	49/6L	59·00	3,150
0·062	49/1	7·81	450	0·187	84/6	54·43	2,850
0·075	19/2	11·00	750	0·218	P36/6B	100·00	4,800
0·075	49/2	9·75	700	0·218	49/6BL	81·25	4,500
0·087	19/2A	15·300	1,000	0·252	P36/7	130·00	6,500
0·087	49/2A	15·000	900	0·252	49/7L	120·00	6,000
0·105	19/2B	18·890	1,400	0·252	133/7	112·50	5,000
0·111	P36/3	25·000	1,400	0·281	P36/8	171·00	7,500
0·111	49/3L	21·000	1,000	0·312	P36/9	215·00	10,500
0·111	84/3	19·500	900	0·312	189/9	180·00	8,500
0·126	P36/4	33·500	1,800	0·375	P36/10	300·00	14,300
0·126	49/4L	28·600	1,625	0·375	189/10	234·00	11,000
0·126	84/4	26·600	1,550	0·438	189/11	350·00	16,000
				0·500	189/12	455·00	21,000

(Sizes 7/51, 7/52, 19/1, and 19/2 were formerly Bowden Inner Members 51, 52, 11, and 12 respectively.)

Power Required for Coiling Wire.—To bend a piece of wire diameter d and length s to a radius r requires the application of a bending moment equal to $p\,\frac{\pi}{32}\,d^3$ where p is the yield stress of the material. The angular displacement of one end of the wire relatively to the other is $\frac{s}{r}$, and so the energy required is $p\,\frac{\pi}{32}\,d^3\,\frac{s}{r}$.

If the wire is coiled at a linear speed of r in. per min., the power required is

$$\left(p\,\frac{\pi}{32}\,d^3\,\frac{v}{r} \times \frac{1}{12 \times 33{,}000}\right) \text{ h.p.}$$

Here $p = 150{,}000$ lb. per sq. in (say).

$d = 0{\cdot}219.$

$v = 75 \times \pi \times 1 = 236.$

$r = \frac{1}{2}.$

Hence h.p. $= 150{,}000 \times \frac{\pi}{32} \times 0{\cdot}219^3 \times \frac{238}{0{\cdot}5} \times \frac{1}{12 \times 33{,}000} = 0{\cdot}185.$

WIRE DRAWING

The fundamental basis of wire production is simple in principle. Thin rods are merely drawn through " dies " or annular openings in blocks of hard metal, whereupon the diameter of the rod is decreased, the rod being pulled out into the form of wire.

A diagram of a modern " die " for the production of copper wire is illustrated in Fig. 2. It consists merely of a tapering hole in a block of metal, the angle of taper being between 11 and 16 degrees. Thick wire or thin rod is reduced in diameter, the reduction in cross-sectional area being, in practice, of the order of 30 per cent.

Most of the wire-drawing factories obtain their raw material from the smelters in the form of coils of metal rod, each coil about 30 ft. in length and about ¼ in. in thickness. Such material is immersed in a bath of strong acid to remove surface scale, after which it is passed into neutralising baths and finally washed and dried. Subsequently the coils are electrically welded together into continuous lengths.

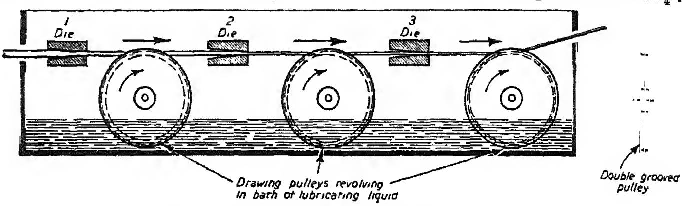


Fig. 1.—Diagrammatic view of a wire-drawing machine, showing manner in which wire is drawn through a series of dies of successively decreasing diameters.

The metal rod is now ready for the drawing process. To this end, it is fed into a machine containing six or more dies, each die being of smaller diameter than the preceding one. By a simple arrangement of pulleys and dies (see Fig. 1), the metal rod is step by step drawn out into thin wire, the wire emerging from the mechanical drawing machine being automatically wound on drums. Such wire, if it has not been reduced to the required diameter, is then fed into another drawing machine containing dies of smaller sizes, and it may even be made to undergo a third drawing-out process before its required diameter or cross-sectional area is reached.

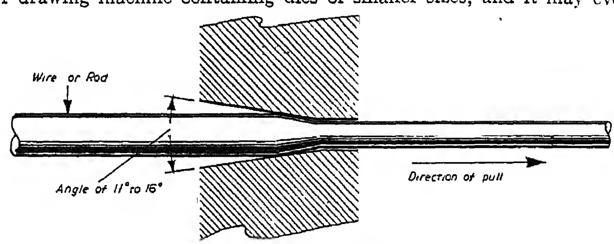


Fig. 2.—Cross-section of a wire-drawing die.

When a metal rod or wire is drawn through a die, a tremendous amount of heat is generated owing to the enormous amount of friction set up, not only at the contacting surfaces of wire and die but also within the wire itself. If this unwanted heat were not immediately and continuously removed, the die would quickly heat up beyond red heat, thereby deforming itself and melting the wire. A wire-drawing machine, therefore, needs continuous lubrication when it is in action. Until recent times this lubrication was commonly obtained by running

the pulleys over which the wire passed in a bath of warm tallow or soapy water. Lubricants similar to this are, indeed, still employed, but in the latest models of high-speed wire-drawing machines, a synthetic lubricant is employed, and this is forced under pressure into the dies, so that each die is continuously swilled all over its bearing surface with the lubricating fluid.

In the olden days, dies of hard iron were employed for wire drawing. Nowadays, of course, much superior materials are used for die-making. Among these may be mentioned alloy-steel, and, in particular, tungsten carbide, a steel-like material which is characterised by an extreme degree of hardness and toughness. These tungsten-carbide dies have been found very satisfactory in the modern high-speed machines which are in operation for many hours each day, since the day-by-day wear on them under such " forced " conditions is extremely small.

For the drawing of wire of less than $\frac{1}{8}$-in. diameter, dies consisting of rubies or even of diamonds are widely used. Such jewel dies are highly efficient in action, and, particularly in the case of diamond dies, they may be used for very lengthy periods without apparent wear or deformation setting in.

Nevertheless, all dies used for wire drawing eventually show signs of wear. Usually this wear takes the form of the die aperture becoming oval instead of perfectly round. When such wear becomes manifest, the die is removed from its holder and is put on a lapidary's lathe, where its aperture is lapped out or enlarged to the next larger size of die aperture by means of a steel rod charged with carborundum powder and continually kept moist with turpentine. In this way a diamond, ruby, or metal wire-drawing die, beginning its working life with an aperture of the smallest size, has its aperture successively increased until, finally, it is given the largest size of aperture. After this, when the die shows signs of serious wear, it is finally rejected.

Modern wire-drawing machines frequently contain a dozen or more dies of successively decreasing aperture sizes, and so efficient are they under actual working conditions that average wire speeds of between 3,500 and 6,000 ft. per minute are attained.

Actually, the wire does not pass through the drawing machine at one constant speed. During the first stages of drawing, when the wire or rod is relatively thick, the drawing speed is comparatively slow. As the wire is thinned out in diameter, however, a higher drawing speed becomes permissible, whilst in the case of very thin wires drawing speeds of nearly 8,000 ft. of wire per minute have been attained.

Not all varieties of wire can be drawn at the same constant speed. Copper, which is a ductile metal, can be drawn at maximum speeds. So, too, can aluminium and some of its alloys. Iron and steel wires, however, cannot be so treated. For them a slower drawing speed must be employed, whilst for the " springy " hard-resistance wires of nickel-silver and similar alloys only a relatively low rate of drawing is permissible.

By using composite wires, it is possible to produce wire filaments of exceedingly small diameter. Perhaps the finest wire which has ever been drawn was a length of pure platinum wire which measured only 1/30,000 in. in diameter. This wire, which was many thousand times smaller than a human hair, and of course quite invisible to the human eye, was made by encasing a platinum wire within a silver wire, the latter being ten times the diameter of the former. By careful drawing, the composite wire was pulled out to a diameter of 1/3,000 in., after which a length of it was immersed in nitric acid. The acid dissolved away the silver, leaving the inner core of platinum intact. In this manner the world's finest wire was obtained.

Very thick wires are frequently produced by hot rolling rather than by drawing. For this purpose " wire bars " consisting of about 4-in. square-section metal are heated to redness and then passed through a series of grooved rolls, whereupon metal " wire " or rod of from $\frac{1}{4}$- to $\frac{3}{8}$-in. diameter is produced. Particularly in the case of hard alloys is this method of producing thick wire employed.

Construction of Wire Rope.—Wire rope is referred to as rope of so many strands of so many wires—ordinarily, 6 strands with 7 or 19 wires to the strand. In cases of 7 wires to the strand, rope would be made up of 42 wires over a hemp core. If made 19 wires to the strand, it would be made up of 114 wires over a hemp core.

Rope is generally made with a hemp centre unless called for with a wire core. Some term it 6-strand rope with wire core, while others call it 7-strand rope of so many wires per strand.

When made of 6 strands of 7 wires each, it is known as *haulage, transmission*, or *standing rope*.

When made of 6 strands of 19 wires each, it is known as *hoisting rope*.

When made of 6 strands of 37 wires each, it is known as *special flexible rope*.

When made of 8 strands of 19 wires each, it is known as *extra-flexible rope*.

When made of 6 strands of 12 wires each, it is generally termed *running rope*.

When made of 6 ropes of 6 strands, each strand containing 7 wires to the strand, it is known as *tiller* or *hand rope*.

Wire-rope cores may be of 7 wires, of 19 wires, or of rope made of 37 wires, depending on the construction and size of the rope.

It is most common to furnish rope of one-size wire construction such as 6 strands of 19 wires, all of one-size wire in the strand.

Three-size wire construction, termed "Warrington" Lay, is of 7 inside wires of uniform diameter surrounded by 12 wires which are alternately large and small. This combination increases the metallic area and strength by approximately 10 per cent. "Warrington" lay is generally made of 6 strands of 19 wires to the strand, with the three-size wire construction, as above stated.

"Seale" Lay is generally made of 6 strands of 19 wires to the strand, construction being the centre wire large, the next layer of 9 wires small, and the outer layer of 9 wires large. These strands produce a rope somewhat stiffer than the first two mentioned.

This type of rope will withstand abrasion. It is used on slopes, planes, and cable roads where no sharp-angle bends are encountered to stress the outside wires. The use of this rope is largely governed by conditions. In this type of rope there is proportionately less metal in the centre wires, although the outside wires contain more metal than in Standard Hoisting Rope.

Cross-sections of Wire Rope.—The illustrations on pp. 720–722 show the cross-sections of wire rope and the various methods of laying up wire ropes, i.e. the number of strands composing the rope.

(A) Hoisting rope—6 strands, each of 19 wires, laid about a hemp core.

(B) Cable-construction Seale Lay—each strand of 19 wires, 9 outer wires, 9 small inner wires, and 1 large centre wire, the several strands laid about a hemp core.

(C) Transmission or haulage rope—6 strands, each of 7 wires, laid about a hemp core.

(D) Galvanised compound running rope—6 strands, each of 12 wires, laid about a hemp core, all in turn laid about a hemp core.

(E) Hoisting rope with wire core—6 strands, each of 19 wires, laid about a wire strand of 19 wires.

(F) Deep well-drilling cable—composed of 6 strands, 8 wires to the strand, laid about a hemp core.

(G) Galvanised steel hawser—composed of 6 strands of 37 wires per strand, laid about a hemp core.

(H) Tiller rope—composed of 6 independent wire ropes, laid about a hemp core.

(I) Galvanised steel hawser and mooring line—composed of 6 strands of 24 wires per strand, laid about a hemp core with an additional hemp core in each strand.

(J) Galvanised steel hawser and mooring line—6 strands, each composed of 12 wires with a hemp core and in turn laid about a hemp core.

(K) Flexible hoisting rope—8 strands, each strand composed of 19 wires, laid about a hemp core.

(L) Extra-flexible hoisting rope—6 strands, each of 37 wires, laid about a hemp core.

(M) Armoured wire rope—with wire centre.

(N) Armoured wire rope—with hemp centre.

Correct Use of Wire Rope.—There are various kinds of wire rope manufactured, one of the most pliable containing 19 wires to the strand, generally used for hoisting and running purposes. The ropes with 12 wires and 7 wires in the strand are better adapted for standing rope, guys, and rigging.

For safe working load, allow one-fifth to one-seventh of the ultimate strength, according to speed, so as to get good wear from the rope. When substituting wire rope for hemp rope it is good practice to allow for the former the same weight per foot which experience has approved for the latter.

Wire rope is as pliable as new hemp rope of the same strength ; the former will therefore run over the same size sheaves and pulleys as the latter, but the greater the diameter of the sheaves, pulleys, or drums, the longer wire rope will last. Sheaves should be scored to diameter of rope. In the construction of machinery for wire rope it will be found useful to make the drums and sheaves as large as possible.

Experience has demonstrated that the wear increases with the speed. It is therefore better to increase the load than the speed.

Wire rope is manufactured with either a wire or a hemp centre. The latter is more pliable than the former and will wear better where there is short bending.

In no case should galvanised rope be used for running rope. One day's use scrapes off the coating of zinc and rusting proceeds with twice the rapidity.

The grooves of cast-iron pulleys and sheaves should be filled with well-seasoned blocks of hard wood, set on end, to be renewed when worn out. This end-wood will save wear and increase adhesion. The smaller pulleys or rollers which support the ropes on inclined planes should be constructed on the same plan. When large sheaves run with very great velocity, the grooves should be lined with leather set on end, or with india-rubber. This is done in the case of all sheaves used in the transmission of power between distant points by means of rope, which frequently runs at the rate of 4000 ft. per minute.

Steel ropes are taking the place of iron rope where it is a special object to combine lightness with strength, but in substituting a steel rope for an iron running rope the object in view should be to gain an increased wear from the rope rather than to reduce the size.

Avoid, if possible, overlapping of wire rope on drums.

For shafts and elevators, the load lifted should not be more than one-tenth of the strength of the rope. Do not subject wire rope to sudden strain. For wire rope to be exposed to intense heat, use one with a wire core rather than with the ordinary hemp centre.

The grooves on drums and sheaves should be a trifle larger than the rope, perfectly smooth and uniform with the surface of the rope.

Wire ropes should run around all sheaves without chafing the sides of the grooves.

Methods of Uncoiling a Wire Rope.—Wire rope is shipped in coils on reels, and should always be unwound by revolving the coil or reel axially, either on a horizontal shaft mounted on bearings, on a turntable or swift, or by rolling on the ground.

Wire rope should never be pulled out from a stationary coil, as this will result in kinks which injure the rope and are almost impossible to straighten out.

Diamond Wire Dies.—Diamond wire dies comprise commercial diamonds drilled and mounted in brass or other metal cases, and are employed in wire mills for drawing wire for electrical or other uses. Their great hardness gives considerable freedom from wear, so that an immense amount of wire of uniform gauge can be turned out before it becomes essential to replace the die. The rough diamonds are first trimmed with diamond points, and then drilled with small drills, fed with diamond powder, and made to oscillate by mechanical means for several hours. Diamond powder must be employed. Once pierced, the holes are formed to the type of metal to be drawn polished to the requisite gauge, and adjusted to within one-ten-thousandth of an inch. They are then mounted in brass cases rather larger than 1-in. diameter and are ready for use. The holes vary in diameter from one-tenth to four-thousandths.

The use of tungsten carbide for wire-drawing dies has increased during recent years. Worn dies are opened out to the next size larger and it is thus economical to buy the rough-pierced carbide pellets from the manufacturers. These are rough pierced to the size ordered, and it is necessary to state when ordering what the diameter of the finished hole is to be. The rough pellets are mounted in suitable casing, the small pellets being press fitted into alloy steel, stainless steel, monel metal, or bronze casing.

The gauges in general use for measurement of screw threads are screw ring gauges which may be of either the "solid" type and allow for no adjustment, or of the "split" type of ring gauge where, by means of incorporated adjusting screws, the ring may, within limits, be either opened out or closed in, thereby allowing the gauge thread diameters to be increased or decreased. Other gauges for this purpose are of the caliper pattern, such as the Wickman or roller adjustable thread caliper gauge.

Checking Thread Gauges.—For the efficient checking of any type of thread gauge it is understood that the elements of a thread are crest radius, root radius, pitch, flanks and flank angles, thread angle (which is the inclusive angle of both flanks relative to the thread axis), depth and thickness of thread, the profile or, as is more usually termed, the form of thread and the actual thread diameters. Such thread diameters are known as full, crest, major, or outside diameter, the effective or pitch diameter, and the core, root, or minor diameter. In this section these thread diameters will be referred to by their workshop terms, which are full diameter, effective diameter, and core diameter. As the thickness of thread is measured at the effective diameter, it follows that this particular diameter is of most importance, and so it follows that it also receives most attention. The effective diameter or effective zone lies midway between the full and core diameter.

The comprehensive inspection of a screw thread gauge entails the checking of the thread elements as individual items. The customary procedure is to check the thread elements in the following sequence. First, the pitch and form of thread, which includes the crest and root radii, the flank and thread angles. This stage is carried out with the use of a suitable mould or impression of the internal thread contour. It is not practicable to examine the thread form of the screw ring by direct visual means.

This impression is projected on to a screen, resulting in the outline of the thread form appearing on the screen at a magnification which is usually 50 to 1. With the use of a master template or profile plate having a correspondingly magnified outline of thread, the profile plate is held in contact with the screen to "match up" with the thread form of the impression on the projector, or what is sometimes called the "shadowgraph." Thus will be shown any errors between the master form and the impression thread form. The crest and root radii may now be examined for "flatted form" correct radius and a uniform blend with the thread flanks. With the use of a protractor there follows the checking of each flank angle, together with the inclusive thread angle. At this stage the individual errors of both flank and thread angles should be noted. For the ultimate checking of the effective diameter any such errors should be tabulated for future reference.

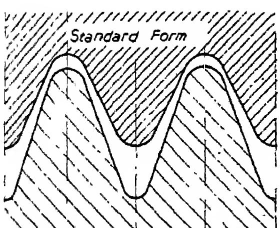
Wax Moulds.—For a good impression of mould of the thread form of the screw ring a modelling wax may be used. An alternative compound may be made up of 70 per cent. of flowers of sulphur mixed thoroughly with 30 per cent. of carbon. Plaster of Paris may also be used. In use, either compound is slowly heated in a large tablespoon or other suitable container. When this wax reaches a liquid molten state, it is quickly poured into the screw ring gauge, which has previously been scrupulously cleaned. The ring gauge is held between blocks to allow sufficient wax to remain in the ring gauge to form an impression of a portion of the ring which, however, must be less than half the gauge thread diameter to allow the wax impression to be withdrawn.

On rather coarse-pitch threads there may be found some difficulty in removing the impression from the ring gauge; in this case it is advisable to very lightly smear the thread with a very thin film of oil or petroleum jelly before pouring in the molten wax. When this wax has set hard and so formed a moulded impression of the thread, the impression may easily be removed from the gauge by turning the gauge upside down and gently tapping it with a mallet, then the impression should fall out of the gauge.

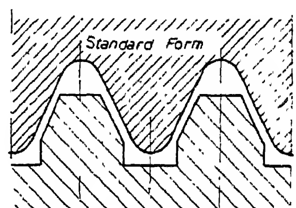
In the checking of the impression on a projector not equipped with micrometer or other direct means of measurement, any errors disclosed when using the master profile may be measured with the use of a rule, preferably graduated in 1/100, 1/50, 1/20 and 1/10ths of an inch. All measurements taken with the rule would, of course, have to be divided by 50 or whatever the projection magnification factor is, to obtain the actual measurement of the impression thread contour.

Any pitch error in the ring gauge will be shown when using the master profile, although on thread gauges of any appreciable degree of required accuracy, it would be essential to use a pitch-measuring machine, as detailed later.

Checking Diameter.—At this stage check the core diameter, and this is carried out with a cylindrical plug gauge which is made to the required core diameter of the ring gauge, and if not a good fit, thereby disclosing a diametral error, this diameter is further checked with the use of slip gauges in conjunction with two "rollers" or suitably ground plug gauges. While using this method test for "out of round," or amount of ovality, by measuring the core diameter at varying points of contact, also finding the core diameter taper, if any. From the notes taken during the impression projection find the measured depth of thread; this dimension multiplied by 2 results in the double depth of thread which, when added to the measured core diameter, results in the full diameter of the screw ring gauge being obtained.



Test plug thread form, cleared at root and flanks for checking full diameter of screw ring gauge



Test plug thread form, cleared at root and crest with correct thread angle for checking effective diameter of screw ring gauge

Fig. 1.—Thread forms for checking individual thread diameters.

Again referring to the impression projection measurement of the thickness of thread form, which for standard forms of thread is equal to one-half of the pitch dimension, find the perpendicular height from this thickness line to the bottom or root radius of thread by means of rule dimension divided by projector magnification factor. Thus the true effective diameter zone distance to the core diameter is arrived at. This dimension when multiplied by 2 and then added to the measured core diameter will result in the effective diameter of the screw ring gauge being obtained. These results are compared with the required print or drawing dimensions, and errors noted.

Test Plugs.—The mechanical checking of screw ring gauges entails the use of thread diameter "test" plugs. Such plugs are made as acceptance check plugs, and are sized to the maximum and minimum allowable limits the gauge is considered to reach, to afford safe and efficient quality control of the work produced, whilst allowing as much limit as possible on such production. The test plugs are so constructed to check the individual thread diameters, the thread form being illustrated in Fig. 1.

It follows that with a full-diameter test plug made to the maximum gauge size, and another similar plug to the minimum diameter, the acceptable full diameter of the ring gauge is thereby determined. Test plugs with a thread form for effective diameter contact only are used for similar checking of the effective screw ring gauge diameter. Core diameter is checked by use of plain cylindrical plugs or by use of slip gauges and rollers.

This gauge inspection procedure of thread gauges for screw rings is exactly similar for thread gauges of the caliper type, the only difference being in the thread form of " Go " and " Not Go " gauges. The " Go " is full form, and the " Not Go " has a thread form for effective diameter contact only.

Use of Balls.—As shown in Fig. 2, two steel balls are selected which, when inserted in the thread groove, protrude slightly inside the core diameter. The balls may be retained in position with the use of petroleum jelly or grease; alternatively, both or either of the gauge or steel balls may be magnetised by contact with a fairly strong magnet or magnetic chuck. The gauge is laid face down on a flat surface, and with balls inserted in diametrically opposite threaded grooves, slips are inserted and the distance between the balls determined. From the following formula, the effective diameter of the gauge is found :

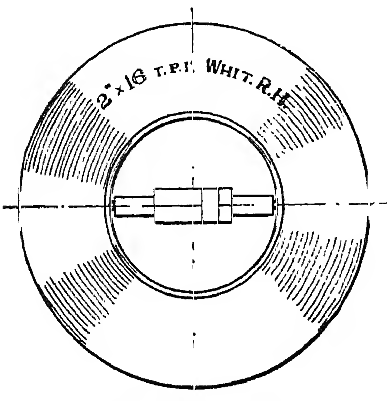


Fig. 2.—Effective diameter of screw ring gauge checked by steel balls, held in thread by petroleum jelly, and the dimension between balls found by slip gauges.

Let A = Effective diameter.
B = Dimension between balls.
C = Mean diameter of balls used.
P = Pitch of thread.
θ = Half angle of thread.

$$\therefore A = (B + 2c) - \left\{ P'' \frac{\cot\theta}{2} - (\operatorname{cosec}\theta - 1)c \right\}$$

By inserting the balls in each consecutive thread and at various points of contact and the varying dimension between the balls noted as shown by slip gauges, the presence of any bell mouth or taper and ovality is easily found. On very coarse threads difficulty may be experienced in holding the slips parallel to the thread. In this case two steel balls in consecutive threads on one side of the gauge and one ball opposite are used to enable the slips being maintained square.

The use of such steel balls will be found useful when used in this manner for the checking of taper thread gauges.

The following standard diameter balls and their corresponding range of thread pitch will be found useful. :

Diameter of steel ball	*Range of threads that may be checked*
$\frac{1}{32}$-in. dia.	15–26 threads per inch
1 mm. ,,	13–21 ,, ,, ,,
$\frac{3}{64}$-in. ,,	10–18 ,, ,, ,,
$\frac{1}{16}$-in. ,,	8–13 ,, ,, ,,
$\frac{3}{32}$-in. ,,	$5\frac{1}{2}$–9 ,, ,, ,,
$\frac{1}{8}$-in. ,,	$4\frac{1}{2}$–6 ,, ,, ,,

The above range is for the Whitworth form of thread. To find the size of ball for metric or American form of thread, the maximum ball diameter is equal to Pitch × 1·008. Minimum diameter of ball = Pitch × 0·508.

Checking Screw Plug Gauges.—The method of checking thread test plugs for the inspection of screw ring gauges is now dealt with. Gauge-measuring appliances for screw thread checking include a male thread-diameter measuring machine of the floating micrometer type, together with a stock of cylinders of

various diameters, which are used on screw plugs in a similar manner to steel balls as used in the checking of screw rings. Such thread-diameter measuring machines have a micrometer unit giving direct readings to 0·0001 in. Usually the barrel or thimble of this micrometer is about 3 in. in diameter, so that a 0·0001 in. actual measurement is indicated by lines engraved at about $\frac{1}{32}$ in. apart, and there is no difficulty in taking readings to 0·00005.

Additional accuracy may be obtained by making a spring clip to fit on the indicator of the thread-diameter measuring machine, this clip holding a magnifying glass giving an enlarged view of indicator pointer allowing of finer adjustment and closer reading as shown in Fig. 3.

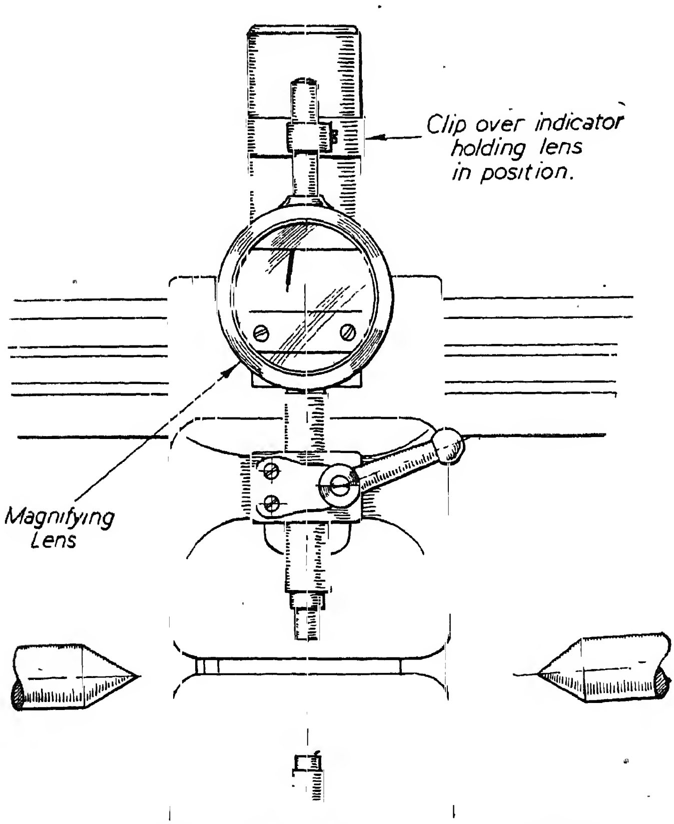


Fig. 3.—Showing magnifying lens held in position by a spring clip for increased accuracy of indicator readings.

A pitch-measuring machine and thread profile projector are also required for the purpose of screw plug checking.

Cylinders.—The measurement of the effective thread diameter and inclusive thread angle calls for the use of thread-measuring cylinders. These cylinders may take the form of silver-steel rod, piano wire or ordinary sewing needles. There are cylinders especially manufactured for the purpose of thread measurement.

Table I shows the needle-packet identification numbers in the extreme left-hand column with the corresponding " mean " needle diameter, followed by the thread forms and pitches for which these needles are suitable for checking. Working in strict accordance with these tables will ensure that the most suitable needle for actual or a very close contact with the pitch-line contact is obtained.

As illustrated in Fig. 4, cylinders which make actual contact with the pitch-line location will result in measurement of the " true " effective diameter being

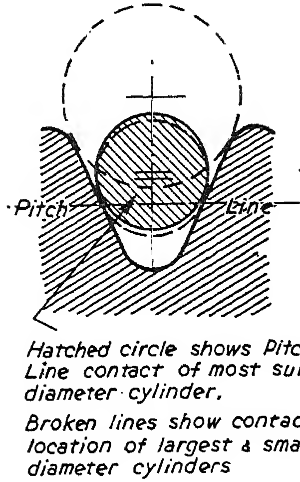


Fig. 4.—Sectional diagram showing the position of the needle in relation to the pitch-line contact.

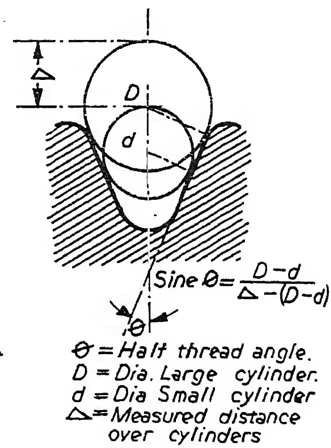


Fig. 5.—Thread-angle measurement using cylinders of different diameters.

obtained, and will be regardless of any flank angle errors which would virtually increase the effective diameter with the use of cylinders, other than pitch-line contact if any such error in flank or inclusive thread angle is present.

When checking effective thread diameters with measuring cylinders which do not make direct contact within a zone in very close proximity to the pitch line, the actual angle of thread which is perpendicular to the thread axis must first be ascertained. If no means of angular measurements is available the inclusive thread angle may be accurately determined as follows :

One cylinder which is of the maximum diameter is placed in the thread groove as shown in Fig. 5, and the dimension from any fixed point is noted when carefully measured. This process is then repeated, using a cylinder smaller in diameter. From the formula is obtained the half inclusive thread angle. Using a series of cylinders of various diameters will also disclose the presence of any indentations or irregularities in the continued straight-line portion of thread flanks. Constants

for the determination of maximum and minimum diameter cylinders are as follows:

Thread Form	*Largest Diameter*	*Smallest Diameter*
American	Equal to pitch	Half pitch
Whitworth	0·85 ÷ No. of t.p.i.	0·51 ÷ No. of t.p.i.
British Association	0·73 ÷ No. of t.p.i.	Half pitch
Metric	Equal to pitch	0·51 ÷ No. of t.p.i.

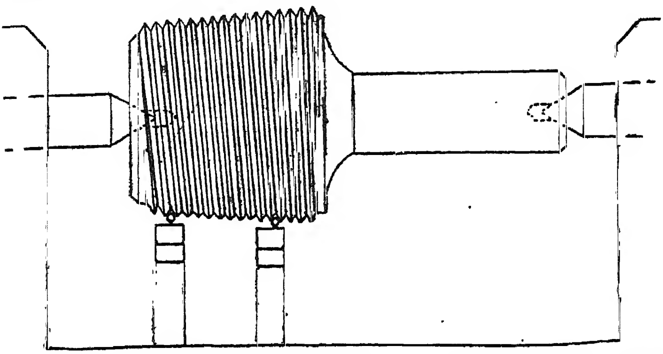


Fig. 6.—For the accurate measurement of cylinders in contact with the thread the arrangement shown above will suffice when thread-diameter machines are not available.

The diameter of cylinder for pitch-line contact equals 0·5 pitch by secant of half thread angle.

For the accurate measurement of cylinders in contact with the thread the arrangement as shown in Fig. 6 will suffice when no thread-diameter measuring machines are available.

This "set-up" shows the checking of the "rate of taper," together with the thread diameters, and on pipe taper thread gauges will be useful to determine the actual thread diameter at any given point or at the small and large ends. Accuracy in measurement with this method makes it essential that the line of centres is "dead parallel" to the base, which must be flat and of a smooth surface, and the perpendicular height must be known to within at least 0·0001 in. (one-tenth of a thousand). Any discrepancies should be noted for future reference.

In use, when the screw plug to be checked has been thoroughly cleaned, especially the "centres," which are best cleaned with an oil-stone dressed to a true 60 degree conical angle, then a very slight film of grease is applied to ensure against friction when the gauge is rotated on the centres when assembled. A needle selected for the form and pitch of thread as indicated in Table I is placed in the thread groove and by "trial and error" the distance from the base to the needle is found with the use of slip gauges.

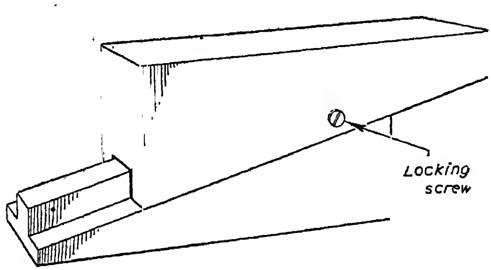


Fig. 7.—Adjustable parallels.

Adjustable Parallels.—For the small businesses which have no such "slip gauges," or for the firms who have any "overload" on the demand for such slips, the writer suggests the use of "adjustable parallels," as illustrated in Fig. 7. Such parallels are simply made and are easily ground flat and parallel when assembled, and also easily reconditioned when worn. These will be found to relieve the demand on the slips and are useful for checking various types of gauges or in use with sine bar set-ups, and remove the "trial and error" process. When of a good slide-fit action the wedges are pressed into contact with work measured and the size found by a micrometer measurement over the wedge faces.

A cylinder of large diameter and a smaller cylinder diameter are first used to determine the actual angle of the thread groove as previously explained. Then a cylinder is selected with a diameter as near as possible to that which is required

TABLE I.—SEWING NEEDLE SIZES FOR THREAD MEASUREMENT

Sewing Needle Packet Number	*Mean Diameter of Needles*	*Whitworth Threads per Inch*	*Metric Pitch*	*Standard Acme Threads per Inch*	*American Standard Threads per Inch*	*British Association Number*	*Cycle Engineers' Threads per Inch*
11	0·015	34/40	—	34	38/40	3 & 4	40
10	0·017	32	0·75	30	32/36	2	36
9	0·020	28/30	—	24	28/32	1	32
8	0·023	24/26	1 mm.	22	24	0	24
7	0·026	22	—	20	22	—	22
6	0·029	18/20	1·25	18	20	—	20
5	0·033	16	1·5	16	18	—	18
4	0·036	16	1·5	14	16	—	16
3	0·038	14	1·75	13	16	—	—
2	0·042	14	1·75	12	14	—	14
1	0·047	12	2 mm.	11	12	—	—
1/0	0·049	11	2·25	10	12	—	12
2/0	0·055	10	2·5	9	11	—	—

to make pitch-line contact, and the dimension from "centres" base to under the cylinder is found. On parallel screw-plug gauges this measurement is repeated in consecutive thread grooves to find presence of any taper. These dimensions being noted, the gauge is rotated through 90 degrees and the measurements taken as before, any variation being noted, and the process repeated when the gauge has been rotated 180 degrees. From the variation of the noted measurements will be discovered the ovality of the thread diameter, together with the eccentricity to the centres. The effective thread diameter is then determined as follows: First find the measurement from under the cylinder to the line of centres. This is obtained by the difference of "slips" dimensions and the distance of base to line of centres. This dimension is then denoted as CD.

Care is taken to avoid distortion of the cylinder which may be caused by an excessive compression of the adjustable parallel (Fig. 8) or the build-up of slip

gauges when in contact with the cylinder. The gauge should be rotated through about 5 degrees, thereby moving the cylinder with it to indicate a correct feel; no movement of the cylinder would disclose the presence of too great a compression, and therefore a tight fit. Measurements of screw plugs with this set-up compare to within 0·0002 in. with measurements obtained on a thread-diameter measuring

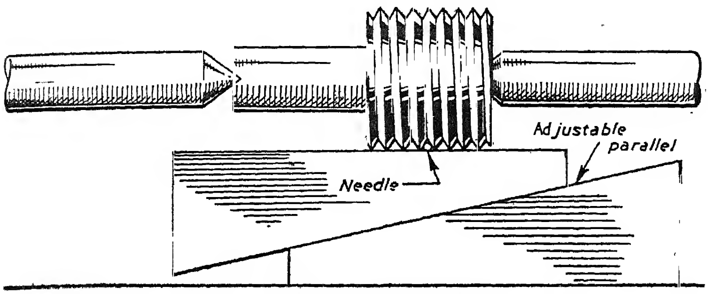


Fig. 8.—Thread and adjustable parallel.

machine. The effective diameter of screw plugs is denoted by " A " and is obtained by the use of the formula :

$$A = 2(CD - d) + \left\{ P\frac{\cot\theta}{2} - (\operatorname{cosec}\theta - 1)d \right\}$$

where A = Effective diameter.
d = Diameter of cylinder used.
P = Pitch of thread.
θ = Half inclusive thread angle.
CD = Difference in measured dimension under cylinder to base, and base to line of centres.

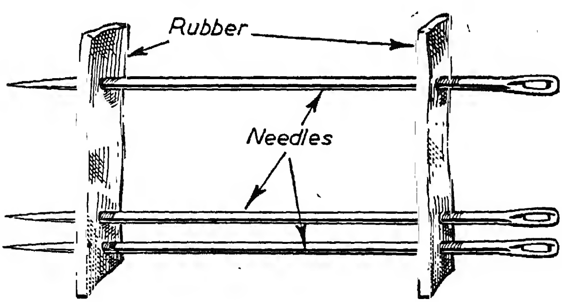


Fig. 9.—Rubber and needles.

The following formula may be used to find the effective diameter of any standard thread form, and is applicable with either the " two-wire " or " three-wire " method :

$$A = M - D + \left\{ P\frac{\cot\theta}{2} - (\operatorname{cosec}\theta - 1)d \right\}$$

where A = Effective diameter as measured.
θ = Half-thread angle.
d = Mean diameter of cylinders used.
M = Measurement obtained over the cylinders when placed in the diametrically opposite thread grooves.

In the absence of a device for supporting the gauges, a convenient means of holding the cylinders in contact in the thread grooves is illustrated in Fig. 9, which shows the cylinders or needles threaded through a suitable piece of thin rubber or an elastic band.

Thread-measuring Machine.—When thread-measuring machines designed for the purpose of screw-gauge inspection are available, the manufacturers' instructions will be adhered to.

When checking screw-plug gauges on a thread-diameter measuring machine care must be taken to make cylinder contact first with the indicator anvil, so that when rotating the micrometer spindle anvil the compression load is released from the rotating anvil face and cylinder, thereby minimising the friction of the cylinders in contact between the thread and measuring anvils. If the cylinder contact is made first with the rotating anvil, it follows that the "winding in" or rotation of the micrometer spindle results in increased anvil face wear, in addition to a "flattening" of the measuring cylinder. Obviating this well-established error of workmanship will result in a much longer period of service and ensuring accuracy of both instrument and cylinders.

Compression Load.—The compression load of the indicator should be periodically checked, as misleading results are obtained with varying compression loads which may be brought about by actual breakdown or weakening of the compression spring, or by the rusting of the spindle and spindle housing, or the entry of grinding dust or other foreign matter.

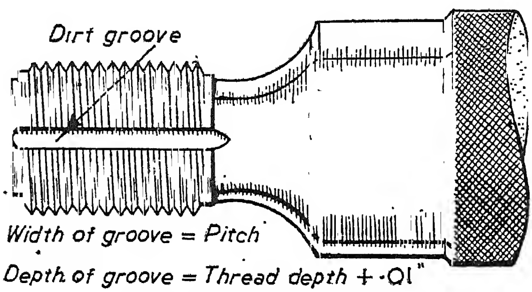


Fig. 10.—Thread showing dirt groove.

The accurate checking of small-diameter gauges with a correspondingly fine pitch makes it essential that a correct compression is applied to the cylinders when in contact with anvil and thread groove.

Floating Carriage.—The floating carriage of the thread-measuring machine should be frequently checked with a spirit level of predetermined accuracy, to ensure the carriage being dead level, and therefore being perfectly balanced and able to remain stationary in any position along the machine "ways" or vee grooves. Any "out of level" errors in the floating carriage would result in a load being applied additional to or less than the indicator compression dependent upon the direction of "run" of this carriage.

Accuracy in thread-diameter measurement with the use of such machines makes it essential that any errors in the thread pitch of the micrometer unit or screw should be recorded, and either a calibration graph or dimensional chart should be in a prominent position near the measuring machine, for reference. Additional checking is necessary to disclose any errors of parallelism of the measuring contact faces, and is carried out by measuring a cylinder which is known to be parallel and truly cylindrical, at different points of location between the anvils and any variation in result noted. The process is repeated with a steel ball in place of the cylinder.

When anvils are in a dead parallel condition a plug of known diameter, and concentric with its centres, is mounted between the work centres; and the measurement obtained is noted and the location of anvils and work is marked. The plug (plain cylindrical) is removed from the machine centres and measured when supported freely by hand, and at the same anvil to work location. Any

variation in the measurement will show an error in the squareness of the floating carriage in relation to the machine axis, the line of centres, and " ways " or vee grooves of the measuring machine.

Setting the Machine.—A convenient method of setting the machine for varying thread diameters will be found with the use of Hoffman or similar rollers of predetermined and calibrated accuracy, provided that the floating carriage and measuring spindle centres are dead at 90 degrees to the machine runways. The addition of a vernier scale to the micrometer unit, together with a means of optical magnification, will enable direct measurement to be obtained to within 0·000005 in. When the thread-measuring machine has been checked, adjusted, and set, the measurement of the simple effective diameter may now be obtained. The actual thread effective diameter can only be determined with the knowledge of all pitch and thread flank errors.

The outside or full diameter of a " Not Go " screw plug is determined by the following formula:

$$\text{"Not Go" Effective diameter} + \frac{\text{Standard thread depth}}{2}$$

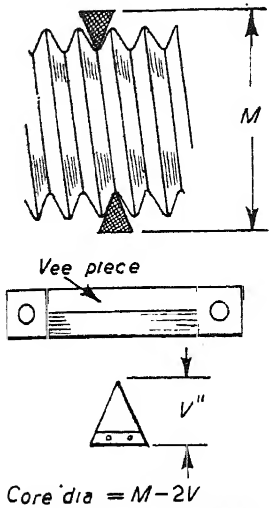


Fig. 11.—Thread and vee pieces.

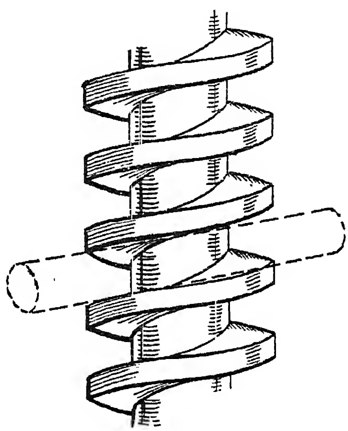


Fig. 12.—Spiral and plug gauge.

On work other than blind holes, less force is necessary to assemble the gauge into the work as the " dirt groove " or air-escape channel immediately removes any foreign matter in the thread and decreases the friction (Fig. 10). The provision of a similar groove in a ring gauge very often increases the life of the gauge, which nowadays is of vital importance.

We now come to the checking of the screw-plug root or core diameter, which entails the use of " vee " pieces, as shown (Fig. 11). The inclusive angle of the vee is made considerably less than the inclusive thread angle being checked, to avoid any interference with the vee slopes and the thread flanks. The radius of the " vee edge " must also be smaller than the root radius to ensure measuring contact with the minimum root diameter. In use, one " vee piece " is held in position in each opposite thread groove, and a micrometer reading obtained over the two vee pieces. The point of contact of each vee with the thread is then marked, and the thickness or vee apex to the anvil face of each vee is measured, and the sum of the vee dimensions so obtained is subtracted from the dimension of vees in the thread contact, which results in the root or core diameter of the gauge being obtained.

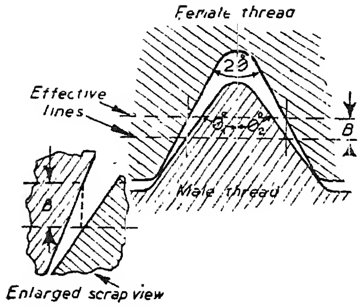


Fig. 13.—Effect of thread angle error.

B = 0·5 resultant eff. dia. difference.

Virtual eff. dia. difference $= \frac{L}{\sin 2\theta^\circ}\left(\theta_1{}^\circ + \theta_2{}^\circ\right)$

$\theta_1{}^\circ$ and $\theta_2{}^\circ$ = Flank angle errors.

L = Diametral length of straight-through flank section.

The illustration (Fig. 12) shows a measuring " transparent cylinder " in contact with the flanks of a " special " thread form.

The angle of inclination, or tilting, of the cylinder is dependent upon, and in direct relation to, the cylinder diameter, the contact-point diameter and the lead or pitch of the thread "grooves." The cylinder when tilted to any noticeable degree when in contact with the thread flanks would result in the measuring cylinder surface making a three-point contact resulting in the contact point of one thread flank being of a different dimension to the cylinder axis. This point is easily grasped when a cylinder is blued with persian blue or similar marking compound, and then put in flank contact with a male thread of coarse helix angle. When removed and examined it will be found that the leading flank will make contact at one point only, due to the spiral curvature at helix of thread. The following or opposite thread flank makes contact with the measuring cylinder at *two* points; the spacing of the points of contact are dependent upon the helix or interference angle of the cylinder, and the spiral path of thread groove.

Determining Correction Value.—The work is first checked with a standard accurate steel ball, the diameter being selected as suitable for " very near " pitch-line flank contact. Only one ball is used in contact with one thread groove and the measurement noted. The steel ball will make a two-point thread flank contact. A measurement is then taken with a cylinder in contact with the thread, the diameter of the cylinder being exactly equal to that of the steel ball. The difference obtained in the measurements will indicate the virtual error in measurement with cylinders making three-point contact relative to correct two-point contact.

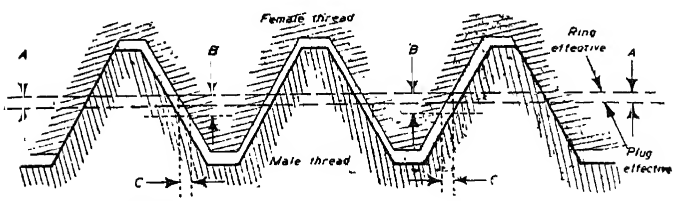


Fig. 14.—Enlarged view of scrap section assembly of male and female U.S.S. thread form with pitch error.

A further point is the compression effect of the cylinders in the thread groove.

To avoid errors due to this distortion, use the lightest possible compression load by fitting an exceptionally light pressure spring to the indicator and contact spindle ; or by means of a spring, the load of which is applied in opposition.

Pitch and Form Errors.—Measurement of such errors will then indicate the actual size of the gauge. The effect of thread angle error is shown in Fig. 13.

In the use of the formula to determine the virtual increase over the obtained simple diameter, the flank angles, denoted by $\theta_1°$ and $\theta_2°$, are measured in relation to the angle of inclination formed by the straight portion of thread flanks to the thread axis. Thus, $\theta_1°$ and $\theta_2°$ are sum of errors of both flank angles, therefore an error of $+20'$ in one flank and an error of $-21'$ in the other, the result in value of $\theta_1°$ and $\theta_2°$ being 41′. Sine $2\theta°$ equals sine of included thread angle when both flank angles are equal.

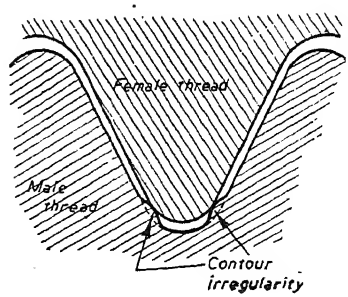


Fig. 15.—Effect of virtual radial thread displacement due to contour irregularity which may not be disclosed by purely mechanical thread-diameter measurement.

The presence of angular errors is best determined with the use of a "projector." A protractor with vernier adjustment is essential.

Accurate outline projection of coarse-helix threads is obtained by projection at corresponding helix setting of separate thread sections.

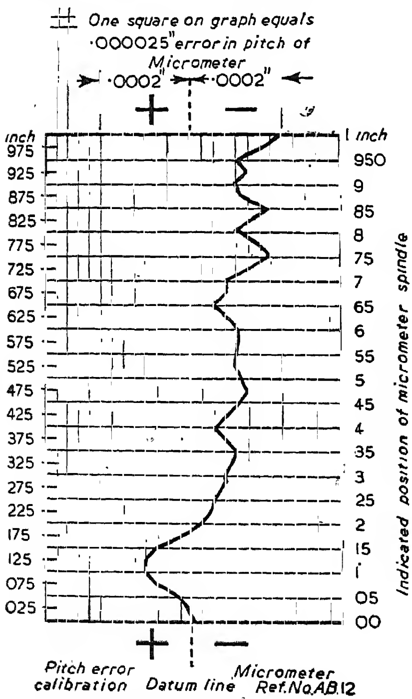


Fig. 16.—Calibrated pitch errors of micrometer of thread-measuring machine.

Pitch Errors.—Virtual increase due to pitch error is illustrated in Fig. 14.

A = Virtual displacement of radial location of effective pitch lines.

B = Resultant difference in mean simple effective diameters.

C = Relative axial displacement due to pitch error in thread contact engagement length as shown.

$C = \frac{B}{2}$ approximately, and A is equal to C. $\therefore B = 2C$ or $B = 2A$.

The exact value of B, which is the virtual difference to simple effective diameter due to such pitch error, is determined as follows:

$B = \text{Pitch error} \times \cot\theta$

Whilst most projection equipment has direct means of pitch measurement, more accurate results are obtained with the use of measuring machines specially designed for this purpose.

Thread pitch errors result in the simple thread

diameters of a male thread being increased virtually. The reverse applies to female threads.

Profile Error.—A further error introducing a virtual difference is shown in Fig. 15, where is shown thread contact with mating form with error in profile of the male thread. Such errors are found by optically magnified examination, as mechanical measurement with vee pieces may not disclose such error.

When checking by optical means the gauge should be examined while being slowly rotated 360 degrees to show any error as illustrated, as well as concentricity errors of root and crest radii. In practice, the latter error is only associated with "cut" threads. Care should be taken in examination for abrasion and warping of the gauge.

When all measurements are taken and any errors noted, the standard of accuracy of the gauge being inspected should then be entered on an inspection report, of which a typical example is shown in Table II.

TABLE II

Gauge No.: G.109. *Suffix No.:* 3a. *Description:* "Go" detail screw plug. *Nominal Dimension:* 1⅛″ × 12 t.p.i. Whitworth form, right hand. *Used On:* Part No. 67. Condenser.

Diameter	*Leading Threads*	*Intermediate Threads*	*End Threads*
Major	Plus 0·0002″	Plus 0·0003″	Plus 0·0004″
Effective	Plus 0·0001″	Plus 0·0002″	Plus 0·00025″
Core	Minus 0·0007″	Minus 0·0007″	Minus 0·0007″

	Leading Flank	*Following Flank*	*Hardness Factor*
Thread angular error	Plus 23′	Minus 37′	61° R.C. Remarks: O.K. for workshop use
Thread profile errors..	Acceptable		
Thread pitch error ..	Minus 0·0003″ in ⅞″ specified length of engagement		

Virtual difference due to errors: Plus 0·00148″

Checked by: J. Smith.
Date: 12th December, 1944.
Accepted/rejected (delete one).

Calibrated Charts.—Accuracy of measuring equipment should be determined, and a chart or plotted graph should be in a prominent position near the instruments, which show at a glance the degree of accuracy of the measuring equipment.

In Fig. 16 is shown a graph of the errors in pitch of the screw of a micrometer unit of thread-measuring machine. Use of such a chart will avoid continual

setting and rechecking with slip gauges, also enabling greater accuracy with required setting when no such dimensional setting pieces are available.

A similar chart showing errors of setting standards, such as "Hoffman rollers," is desirable, and may be tabulated as in Table III.

TABLE III.—ERRORS IN SETTING PIECES FOR MEASURING MACHINE

Nominal Size (in).	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
Diam.	−1	+1	+2	+2	OK	+2	+2	+1	+1	OK	OK	+2	−1	+2	OK	−1
Length	OK	−3	OK	−3	+1	−1	+3	OK	+1	+2	−1	OK	OK	+3	+1	+1

Dimensional errors of rollers in units of 0·000025″ (quarter-tenths)

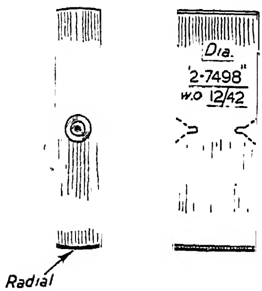


Fig. 17.—"Master" diameter standard for setting of thread-diameter measuring machine.

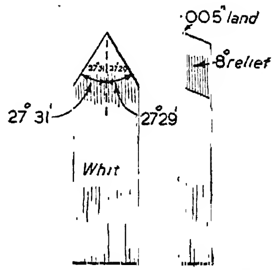


Fig. 18.—Precision-ground "master" angle standard for reference in optical measurement of thread profile.

Reference Standards.—For the accurate setting of the thread-measuring machine, reference standards, a typical example of which is shown in Fig. 17, are used.

The material used should be well seasoned, hardened and ground, care being taken with the centres, and made in sets, the sizes of which will be governed by the work size mostly used.

As the measuring machine is set when the reference standard is held in the work-carrying centres, it follows that measurement of standard should be determined relative to its centres. The obtained dimension should be clearly marked on the standard.

Accuracy of projection equipment should be periodically checked. For angle measuring a reference standard as shown in Fig. 18 is used.

A screw plug of accurate pitch of thread should be kept for reference in checking the projected pitch outline. The writer would suggest that manufacturers should make it a practice of including such reference standards as an accessory of projection equipment.

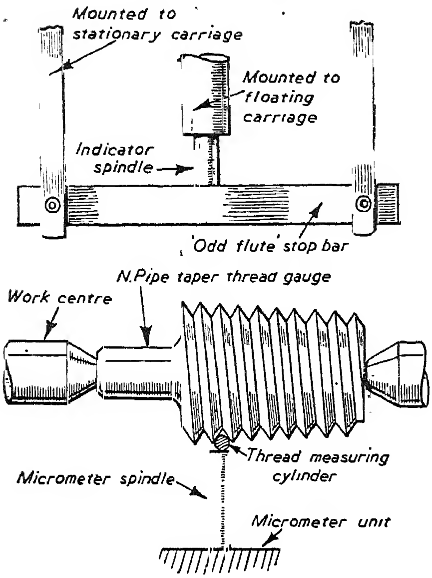


Fig. 19.—Thread-diameter measuring machine "set up" for measuring taper-thread plug gauge.

Checking Taper Screw Plugs.—A set-up of thread-diameter measuring machine for checking of screw taper plugs is shown in Fig. 19. Measuring of taper male thread diameters is usually carried out with one measuring cylinder and using "odd-flute" carriage. Where no odd-flute attachment is available, the simple arrangement shown in Fig. 20 will serve the same purpose.

From these illustrations it will be seen that measurement is taken from the line-of-centres. The setting of the machine with a plain cylindrical plug is first carried out by setting the micrometer reading exactly half of the plug diameter, so that measurement of the taper thread over the cylinder dimension would be doubled, from which is computed the effective diameter.

This is the method generally adopted for measuring thread diameters of taps with an unequal number of threaded flutes.

Truncated Threads.—To determine the amount of thread truncation for checking truncated diameter of "Not Go" screw plug or screw ring gauge, the following formula gives the truncation values of standard forms of thread, and is accepted generally in gauge-making and gauge-inspection practice (Fig. 21).

h = height of fundamental triangle.

T″ Truncation of thread.

Truncated thread diameter of "Not Go" screw plug gauge =

"Not Go" effective diameter + $\frac{h}{3}$.

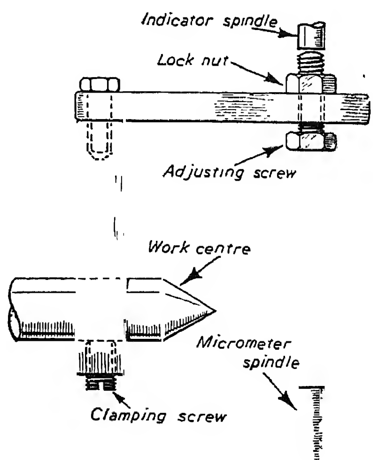


Fig. 20.—Bracket clamped to work-carrying centre for "odd flute," or one-wire method of diameter measuring of taper threads.

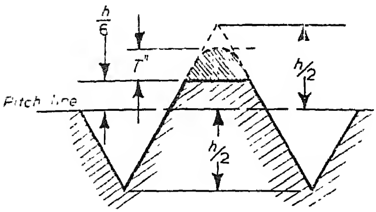


Fig. 21.—Truncation of thread form.

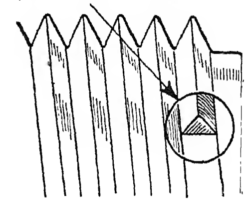


Fig. 22.—Butt end of thread.

Truncated thread diameter of " Not Go " screw ring gauge or thread caliper =

$$\text{"Not Go" effective diameter} - \frac{h}{3}.$$

Value of h for any form of thread with equal flank angles =

$$h = \frac{P}{2}\cot\theta$$

where P = pitch of thread and θ = flank angle.

Butt End of Thread.—A frequent source of trouble is shown in illustration Fig. 22. In the grinding away of the " feather edge " of thread, it is often found that distortion takes place in the " butt end " of the thread. Particular care should be taken in pitch and diametral measuring of the end threads. The distortion at this region usually introduces local pitch error and increased thread diameters, and is pronounced for about one-eighth length of the end thread portion.

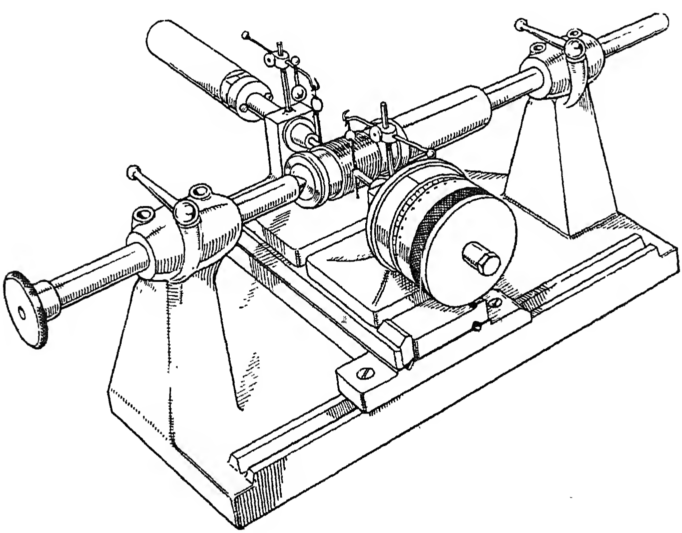
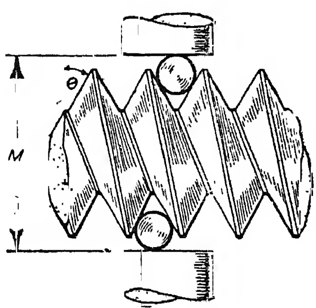


Fig. 23.—Typical thread-diameter measuring machine.

TABLE IV.—TABLES SHOWING VIRTUAL DIFFERENCE FROM EFFECTIVE DIAMETER (RELATIVE TO MEASURED ERRORS IN PITCH OF THREAD)

55°	60°		55°	60°	
Whitworth	*U.S.S., C.E.I., and S.I.*	*Measured Errors in Pitch of Thread*	*Whitworth*	*U.S.S., C.E.I., and S.I.*	*Measured Errors in Pitch of Thread*
"Virtual Difference"			*"Virtual Difference"*		
0·0000480	0·0000433	0·000025	0·0010565	0·0009526	0·00055
0·0000961	0·0000866	0·00005	0·0011526	0·0010392	0·0006
0·0001441	0·0001299	0·000075	0·0012486	0·0011258	0·00065
0·0001921	0·0001732	0·0001	0·0013447	0·0012124	0·0007
0·0002401	0·0002165	0·000125	0·0014407	0·0012990	0·00075
0·0002881	0·0002598	0·00015	0·0015368	0·0013856	0·0008
0·0003361	0·0003031	0·000175	0·0016328	0·0014722	0·00085
0·0003842	0·0003464	0·0002	0·0017289	0·0015588	0·0009
0·0004825	0·0004330	0·00025	0·0018249	0·0016454	0·00095
0·0005763	0·0005196	0·0003	0·0019210	0·0017321	0·0010
0·0006723	0·0006062	0·00035	0·0028865	0·0025981	0·0015
0·0007684	0·0006928	0·0004	0·0038419	0·0034642	0·0020
0·0008644	0·0007794	0·00045	0·0048019	0·0043300	0·0025
0·0009605	0·0008660	0·0005	55°	60°	Pitch error



Where E = Effective diameter, i.e. "Simple Eff."

d = Mean diameter of wires used.

θ = 1 half of thread angle.

M = Measurement over wires

A = Constant (from Tables V and VI).

Then $M = E - A + Bd$.

And $E = M + A - Bd$.

Constant " B " = cosec θ + 1.
For B.A. thread form = 3·48295.
For Whitworth thread form = 3·16568.
For U.S.S. or 60° standard form = 3·00000.
E.g. ½ in. 16 t.p.i. Whitworth form male thread using 0·0350 in. diameter wire.

$$M = 0{\cdot}4600 - 0{\cdot}06003 + (3{\cdot}16568 \times 0{\cdot}0350) \text{ in.} = 0{\cdot}510768 \text{ in.}$$

Applicable to either 2-wire or 3-wire measurement.
Value of constant " A " for any form of thread is equivalent to:

$$\frac{P''}{2} \cot \theta$$

where P″ = pitch of thread and θ = 1 half including thread angle.

TABLE V

No. of T.P.I.	Value of " A " Constant		" Best " Wire Diam.	No. of T.P.I.	Value of " A " Constant		" Best " Wire Diam.
	56° Whit-worth	*60° U.S.S., etc.*			*55° Whit-worth*	*60° U.S.S., etc.*	
2	0·480245	0·433013	0·281	19	0·050552	0·045580	0·030
4	0·240122	0·216506	0·144	20	0·048025	0·043301	0·029
6	0·160082	0·144338	0·093	22	0·043659	0·039365	0·026
8	0·120061	0·108253	0·072	24	0·040020	0·036084	0·023
10	0·096049	0·086603	0·057	26	0·036942	0·033303	0·022
11	0·087317	0·078729	0·053	28	0·034303	0·030929	0·020
12	0·080041	0·072168	0·048	32	0·030015	0·027063	0·018
13	0·073883	0·066617	0·044	36	0·026680	0·024056	0·016
14	0·068606	0·061859	0·041	40	0·024012	0·021651	0·014
15	0·064032	0·057735	0·038	48	0·020010	0·018042	0·011
16	0·060030	0·054127	0·036	60	0·016008	0·014434	0·009
18	0·053360	0·048112	0·032	72	0·013340	0·012028	0·008

Thread Data Sheets.—Table IV gives the value of virtual difference to thread diameters for any given measured pitch error. It must be remembered that pitch error in male thread will virtually "increase" the measured thread diameters. Female or internal threads are virtually decreased due to pitch error.

In Table VII will be seen blank spaces. These spaces enable entry of the " C " constant value, and this value is computed from the diameters of thread-measuring cylinders available.

Thread-measuring Machines.—For the accurate measuring of male thread diameters, machines are specially designed for this purpose, a typical example of which is illustrated in Fig. 23.

Presence of errors in thread pitch considerably affects results obtained from diametral measurement and results in virtually increasing the diameters of male threads.

TABLE VI.—B.A. THREADS

B.A. No.	*Constant "A" Value*	*Best Wire Diam.*	*B.A. No.*	*Constant "A" Value*	*Best Wire Diam.*	*B.A. No.*	*Constant "A" Value*	*Best Wire Diam.*
0	0·0447375	0·021	5	0·0263971	0·013	10	0·015681	0·008
1	0·0402604	0·020	6	0·0237153	0·012	11	0·013863	0·007
2	0·0362377	0·018	7	0·0214767	0·010	12	0·012499	0·006
3	0·0326583	0·016	8	0·0192382	0·009	15	0·009432	0·004
4	0·0295220	0·014	9	0·017499	0·008			

The type of pitch-measuring machine practically in universal use is shown in Fig. 24.

Measuring Thread Diameters.—From experience it is acknowledged that discrepancies in fine measurement are unavoidable unless control is made of the "load" or pressure exerted upon measuring contacts.

Such pressure control in the thread-measuring machine is governed by the incorporated indicator which is designed to eliminate errors due to the personal element with regard to the "feel" of the micrometer and to ensure that measuring is carried out at uniform pressure. At a zero reading the standardised pressure in this country is maintained between 5 and 11 oz., and is used for all thread measuring regardless of diameter to pitch ratio.

The magnification factor of the type of indicator shown in Fig. 23 is approximately 180 to 1, so that 0·0001 in. would appear equivalent to 0·018 in. movement

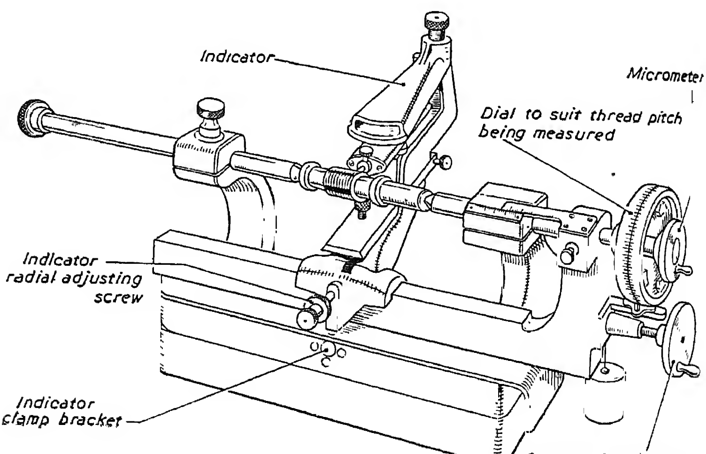


Fig. 24.—Thread-pitch measuring machine.

TABLE VII.—AMPLIFIED FORMULA

$M=E+C$. $E=M-C$. $C=Bd-A$

Value of Constant " C "

Whitworth	*T.P.I.*	*American 60°, etc.*	*Whitworth*	*T.P.I.*	*American 60°, etc.*
	2			22	
	4			24	
	6			26	
	8			28	
	10			32	
	12			36	
	13			40	
	14			48	
	16			60	
	18			72	
	19		55°	T.P.I.	60°
	20				

B.A. THREAD

Value of Constant " C "

No.		*No.*		*No.*	
0		5		10	
1		6		11	
2		7		12	
3		8		15	
4		9			

Value of " C " constant should be calculated from diameter of cylinders in stock, and entered above.

of indicator pointer, thus enabling repetition of readings to within 0·00001 in. The indicator being horizontally positioned does not afford of very easy reading when the machine is used at average bench height with the operator seated. Such discomfort is overcome by fitting a spring-clipped mirror as shown in Fig. 25. The arrangement allows of easier sighting resulting in more assured accuracy of readings.

Diagram of sequence of diameter measuring is shown in Fig. 26.

Work parts which are held on " centres " truly aligned are first measured by contact of indicator plunger and micrometer anvil previously scrupulously cleaned

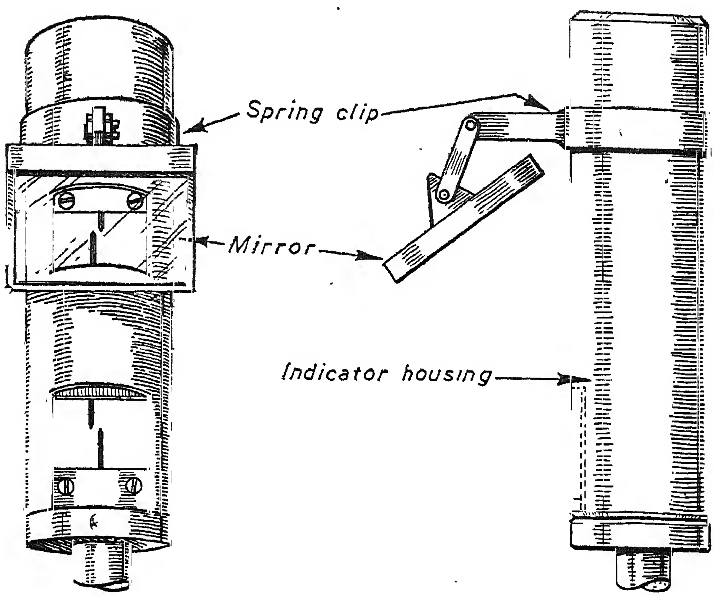


Fig. 25.—Indicator, with mirror allowing for easier sighting.

and set to full diameter of work-piece by means of " slip " gauges, Hoffman rollers, or preferably with accurate centred cylindrical plug gauge.

Use of thread-measuring cylinders enables measuring of "simple" effective diameter as explained previously.

"Vee pieces" or prisms are used for core diameter measuring.

To ensure even distribution of wear the saddle carriage and " floating micrometer " should be used over the full capacity of the machine runways whenever possible, and will assist in maintaining the floating carriage at right angles to the base runways.

If it is found that erratic measurement results when the work is held on centres and then " free of centres," thus disclosing out of squareness of measuring unit, the realignment is carried out by " eccentric conical peg " as illustrated in Fig. 27.

Preventing Distortion of Measuring Contact Pressure.—To prevent distortion of measuring contact pressure the machine should be dead level, otherwise inclination will result in floating carriage eliminating or increasing virtual pressure of indicator unit. The checking for the machine being level may be carried out by precision block or "slip" gauge held in contact by measuring anvils and a spirit level mounted on such block thereby disclosing any "out of level" run.

Contact pressure should be periodically checked by mounting the indicator vertically in vee block, plunger uppermost, which is loaded with weights until the pointer is at zero. The weight should be between 5 to 10 oz.

It is rarely found that erroneous pressure is due to spring fatigue, the usual source of trouble being due to stickiness of plunger assembly through "rusting" or oil flaking.

Pitch Measurement.—Work parts to be measured are held between centres similar to the diameter measuring machine and a stylus or contact-finger is selected to make contact on the pitch diameter line as shown in Fig. 28.

Work-carrying centres are held in medium contact with work previously scrupulously cleaned, the dial as shown in Fig. 24 is selected suitable for the pitch of work being measured. The indicator is adjusted to zero reading and traversed up the flank, to and over the crest, and into the next adjacent thread until the indicator again reads zero.

Pitch error is noted by the dial and the graduated fixed dial which affords measured dimensions by direct readings of 0·0001 in., and readings may be determined to within 0·00005 in.

As pitch "measured accuracy" is governed by accuracy of pitch of the machine screw, it follows that knowledge of "machine accuracy" is essential and is frequently checked with a reference screw and results are plotted graphically as shown in Fig. 29.

Thread Caliper Gauges.—A typical caliper gauge is that of the Wickman pattern. A line drawing showing constructional features appears in Fig. 30.

From a "gauge inspection" viewpoint, it is easier and of a more definite degree of resultant accuracy to recheck or determine the virtual thread diameters of caliper gauges compared with ring gauges.

As seen from Figs. 30 and 31 the construction of thread-gauging anvils ensures complete thread profile contact,

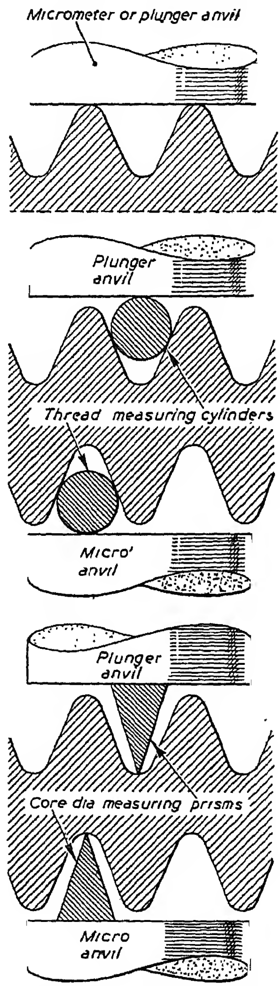


Fig. 26.—Measuring male thread diameters.

and front relief eliminates errors of contact associated with variant thread helices. Gauge anvils of "Go" section are of nominal full form thread profile; "Not Go" gauge anvils have only two opposed thread contour sections and are truncated proportionate to root radius. Clearance is provided at crest radius, thus ensuring contact at effective zone for two adjacent threads, thereby avoiding errors of pitch and root and crest diameters. Form of thread of "Go" and "Not Go" anvils is shown in Fig. 32.

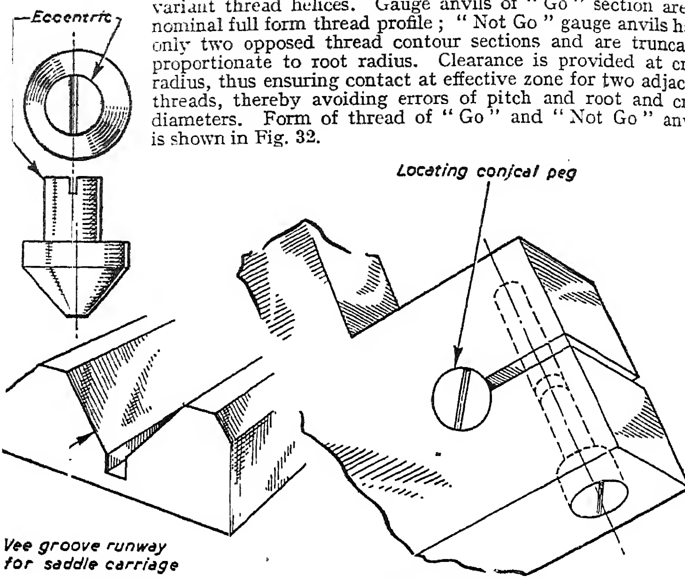


Fig. 27.—Constructional features of machine alignment and adjustment.

As thread teeth are of annular location and therefore do not lie in a helical plane, the caliper gauge will check both right-hand and left-hand threads, work thread diameters making line contact only with the gauge thread profile.

Thread Caliper Gauge Setting.—With the use of a peg spanner (Fig. 30) or screwdriver it is a simple matter to set the caliper gauge, within its range, or within 0·0001 in. Detailed instructions are not given as study of the illustrated construction makes this matter self-explanatory.

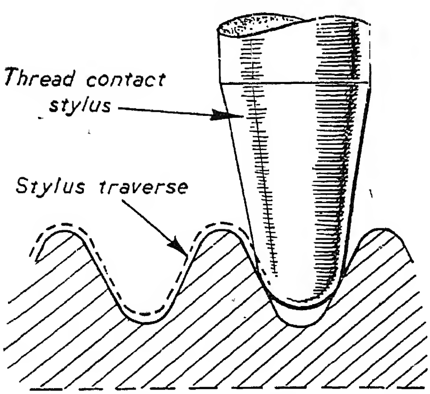


Fig. 28.—Thread flanks in contact with stylus of pitch-measuring machine.

If no thread setting plug is available, the setting or checking may be carried out with the use of slip gauges, adjustable parallel, or a plain cylindrical plug of the required dimensions. Expressed as a formula, the dimensions of slips, etc., may be determined as follows.

For setting "Go" anvils:

X = nominal maximum core diameter $- W$.

For setting "Not Go" anvils:

X = minimum effective diameter $- (D - T)$;

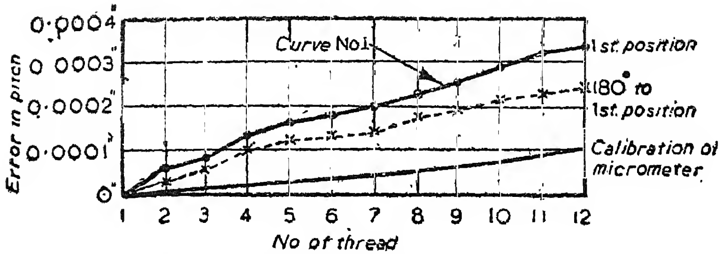


Fig 29.—Calibration graph of measured work pitch error and machine pitch reference error.

where X = slips dimension
W = allowance for wear
D = nominal depth of thread
and where T = truncation value of both " Not Go " anvils.

The value of T for each " Not Go " anvil is marked on the front caliper side of each anvil; thus, for example, if each anvil is marked T = 0·010 in., then the value of T in the formula becomes 0·020 in.

Wear Allowance.—It will be noted that no allowance for wear, i.e. W, is catered for in the " Not Go " setting, such wear allowance that does take place in use will reduce the work tolerance and is therefore safe in production.

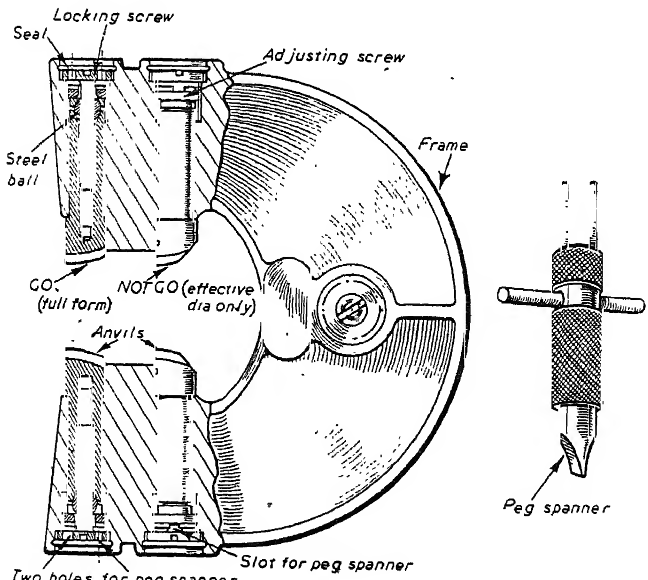


Fig. 30.—Showing the construction of the Wickman type of adjustable thread caliper gauge and details of the special peg spanner.

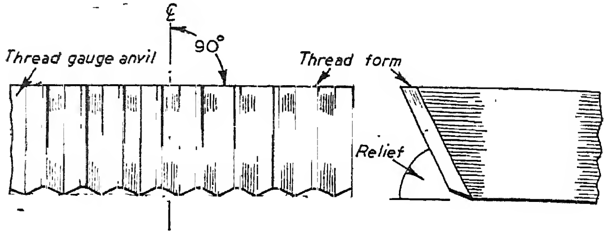


Fig. 31.—Showing the annular location of thread profile and front relief, thus allowing gauging of both right- and left-hand threads and avoiding helical errors of contact.

Wear allowance for the "Go" setting in practice is accepted generally as 0·0003 in., although, of course, it may be varied dependent upon the class of work.

It follows that one great advantage of the caliper gauge is that it allows the maximum tolerance of the work being available. It will be appreciated that a considerably greater wear allowance has to be made with screw ring gauges to ensure a reasonable life of service before becoming oversize.

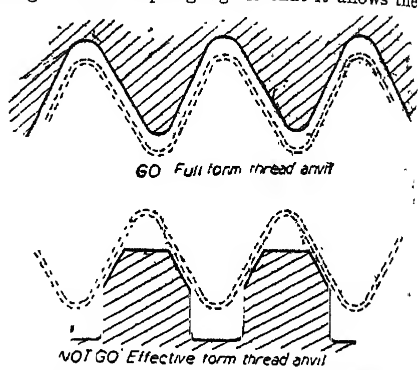


Fig. 32.—Thread profile of Wickman-type gauge anvils. The dotted line shows the standard work-thread form and gauge zone of contact.

Other advantages of the adjustable thread caliper gauge are as follow:

It readily discloses thread diameter ovality, and is speedier in use, as the work does not have to be screwed into and out of the gauge as with ring gauges.

It has ample facility for sealing and marking with identification symbol or monogram, thus making tamper-proof.

A wide range is covered by the gauge. For example, the work to be produced has thread diameters of $\frac{1}{4}$ in. × 26, $\frac{7}{32}$ in. × 26, and $\frac{9}{32}$ in. × 26 t.p.i. Screw ring gauges entail the use of gauges made for each individual size, but it will be found that a $\frac{1}{4}$ in. × 26 t.p.i. caliper gauge embraces also the range of both the $\frac{7}{32}$ in. and $\frac{9}{32}$ in. thread diameters. Resetting enables one gauge to check the three thread diameters.

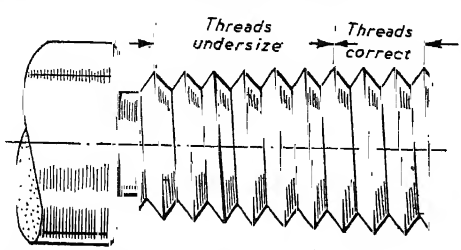


Fig. 33.—Tapered thread, acceptable to ring gauges, although the rear threads are undersize. The error is disclosed by the thread caliper gauge.

When worn, the gauge is easily reconditioned by grinding anvil top faces to remove 0·001 in. to 0·003 in., which removes the worn thread section.

Ring Gauges.—A further advantage of caliper gauges was found when the

work thread by the multipleform thread milling process was checked with ring gauges and found acceptable. Further checking with the caliper gauge proved that the work was "back-tapered," the rear threads being undersize as shown in Fig. 33. The product as shown was threaded up to a shoulder so that the front few threads to size did not allow assembly of the "Not Go" screw ring gauge.

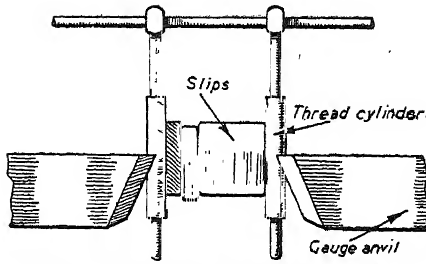


Fig. 34.—Alternative method of setting or checking the thread caliper gauge.

Only two thread sections at the anvil end allowed checking of rear undersize threads independent of the front threads. Investigation proved that such taper was due to misalignment of the headstock, together with cutter flutes of the coneccentric relieved thread milling hob being out of parallel to the thread hob axis.

A further method of setting or checking a thread caliper is shown in Fig. 34. Fig. 35 illustrates the means of comparing the sensitiveness of similar thread calipers by determination of weight necessary to pass work through the anvils.

Screw Thread Micrometer.—With the use of a thread micrometer the diametral thread errors relative to the threads are easily disclosed, indicating the degree necessary to either reduce or increase the work thread diameters.

Fig. 36 shows at A the general conception of a screw thread micrometer and B the basic principle of anvils for conversion of a standard type micrometer for thread measurement.

Sketch C of Fig. 36 shows the type of micrometer for thread depth or thread core diameter measuring. In use the "outside" or major diameter is first determined, after which the thread core diameter is measured. The difference in both micrometer readings will indicate the dimensional depth of thread, the double depth of thread from the major diameter indicating the core diameter. Sketch D of Fig. 36 shows the anvil details and construction. The main points to note are that inclusive anvil angle is smaller than the thread angle of work and that radius (if any) at apex is considerably smaller than thread root radius which it will contact. Any eccentricity of root and major diameters is easily found with this type of micrometer.

In sketch A, Fig. 37, is shown a thread micrometer with "ball-ended" rotating anvil as used for "simple effective" and thread angular measurement. Sketch B shows a pair of anvils with steel balls of different diameter for simpler determination of thread angular measurement. Greater scope is offered by the use of the anvil as shown in C, Fig. 37, which is female centred to accommodate a larger variation in diameters of steel balls.

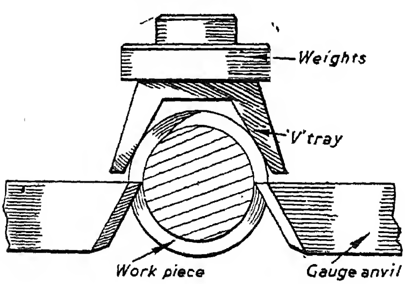


Fig. 35.—Comparative check of sensitiveness of thread caliper gauges.

It will be appreciated that used singly or in combination, these micrometers offer a reliable source of measurement of the thread elements such as "simple" effective diameter, depth of thread and inclusive angle of thread as well as core diameter.

For obvious reasons the range of thread pitches and form is restricted, for the latter, by the anvil angle,

i.e. for each standard thread angular profile a corresponding anvil angle is necessary such as 60 degrees for American and metric form of thread and 55 degrees for standard Whitworth.

Pitch Range.—From Fig. 38 it will be seen that the apex of the micrometer anvil is truncated, and it is this value of truncation that governs the pitch range embraced by the thread micrometer which is determined relative to the length of the straight portion of the thread flank. It follows that the micrometer will measure such a range of threads where the largest thread pitch will make contact

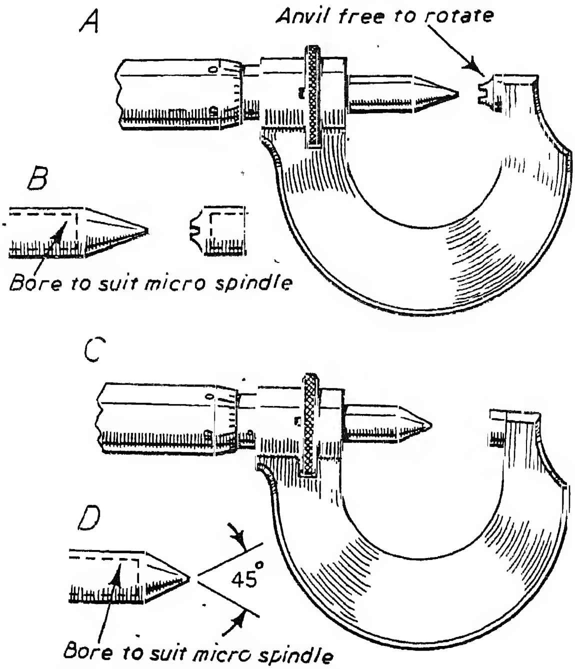


Fig. 36.—A, micrometer for screw thread measuring; B, anvils for converting ordinary micrometer for screw thread measuring; C, micrometer for measuring depth of thread and thread core diameter; D, anvil for converting ordinary micrometer for depth of thread and thread core diameter measuring.

with the micrometer anvil locating at the thread flanks down to the root radius, less the depth of rounding, and the smallest pitch of thread will contact the anvil at the major diameter less the depth of rounding.

Commercially, thread micrometers for Whitworth form of thread in the following ranges are available :

5 to 8	t.p.i.
8 to 12	,,
14 to 20	,,
22 to 30	,,
32 to 38	,,

And so one thread micrometer would be required for each above range of threads.

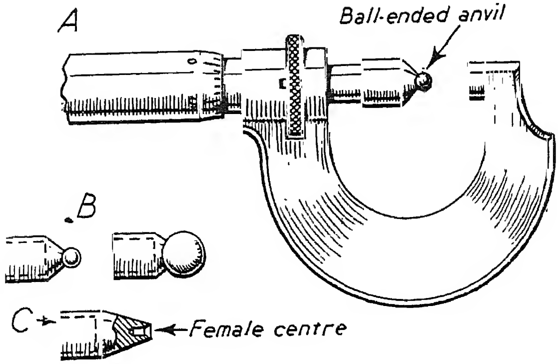


Fig. 37.—A, micrometer with ball-ended anvil for measurement of thread angle ; B, bore to fit micrometer spindle ; C, alternative type of anvil with female centre for accommodating various diameter steel balls for thread angle and simple effective diameter measuring.

Fig. 39 shows the thread micrometer in engagement with work, illustrating also the clearance at the base of flanks of " base anvil " or " female anvil."

The solid type of screw thread ring gauge affords no means of adjustment. A typical screw ring gauge is shown in Fig. 40.

Fig. 41 shows a " split " type of screw ring gauge, where, by means of incorporated adjusting screws, the gauge may be locally upset, thus either increasing or decreasing the virtual thread diameters. A well-tempered gauge should allow sufficient spring to enable setting within 0·0015 in. of its nominal diameter, and yet maintain reasonable concentricity. From the enlarged sectional view of the adjusting screw, Fig. 41, it will be noted that one screw also acts as a dowel, so keeping the split thread helices in alignment.

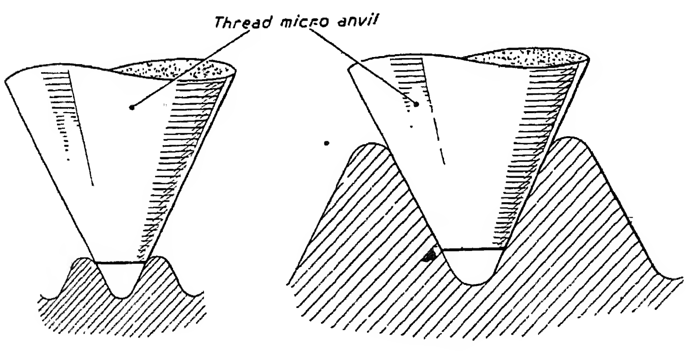


Fig. 38.—Showing limitation of thread pitches which thread micrometer anvil will accommodate.

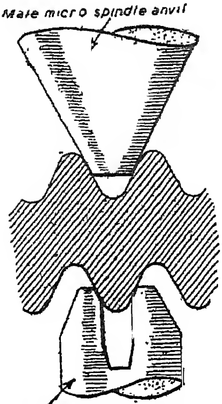


Fig. 39.—Application of thread micrometer in use.

Split Screw Ring.—The main advantage of the split screw ring, compared with the solid type, lies in the fact that the adjustable gauge may be set smaller than its nominal size, thus allowing of definite checking of work parts that have a metal spraying, plating, varnish, lacquering, etc., operation following the thread-forming process. After such a metal-finishing operation, the gauge may be reset for checking of the "coated" threads. Use of solid screw gauges would necessitate separate gauges for "before" and "after" plating of the work.

Adjustable Gauge.—In addition, the adjustable gauge may be set to the maximum permissible diameters, thus obviating, where practicable, the allowance made in respect of the gauge wearing tolerance. When the gauge wears oversize, it may be reset smaller than its nominal size, and then lapped to correct the thread form, and also remove any bellmouth and/or ovality. In use where it is standard practice to work to individual gauges for workshop and inspection tolerances, the same adjustable gauge, by resetting, may be used by workshop and then set for final inspection use.

Whilst greater care is essential when using an adjustable gauge, as its construction makes it more liable to distortion, in actual practice it is found that the adjustable gauge will give about five times the service of a solid gauge.

Split-block Gauge.—Another type of adjustable screw thread gauge, which was very popular many years ago, is shown in Fig. 42. This "split-block" type of gauge was imported into this country from Germany. Nowadays its use is usually confined to the checking of mass quantity-produced taps.

For checking taper-threaded members, such as American national pipe, usually

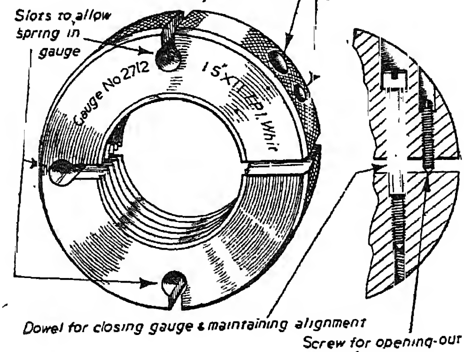


Fig. 40.—Adjustable screw ring gauge.

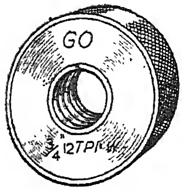


Fig. 41.—Solid-type screw ring gauge.

referred to as Brigg's taper, and other tapered screws, it is general practice to use the solid type of screw ring gauge as shown in Fig. 43.

From the illustration it will be seen that a step, equivalent to twice the pitch of thread, governs the work-diameter tolerance. Taper screws of commercial quality are usually based on a nominal diameter with a permissible gauging allowance of plus and minus one pitch length of thread. Thus the basic or nominal gauge effective thread diameter would be midway between the maximum and minimum gauge step. Another type of screw ring gauge for checking taper threads is shown in Fig. 44. This type is of almost universal use in America and Canada, and it will be noted that there is no step on this type of gauge.

One side of the gauge has the thread diameter of basic size and in use the work parts are allowed to screw into the gauge within plus or minus one thread from this basic side of the gauge. The latter gauge is sometimes used in conjunction with a plain step or depth gauge to guard against error of human

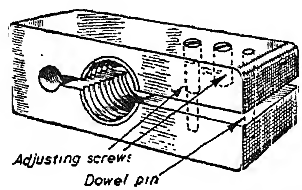


Fig. 42.—Split-block type adjustable screw thread gauge.

element, possible when the plus or minus one thread is determined solely by visual examination.

Grading of Taper Screws.—Fig. 45 shows the basic principle of a gauge for the grading of taper screws, an operation frequently necessary on good-class work. The illustration is self-explanatory.

One advantage is that on work parts threaded close to a shoulder, the use of a limit slip gauge in conjunction with a screw ring gauge will check the squareness of the shoulder seating face with the thread axis (see Fig. 46).

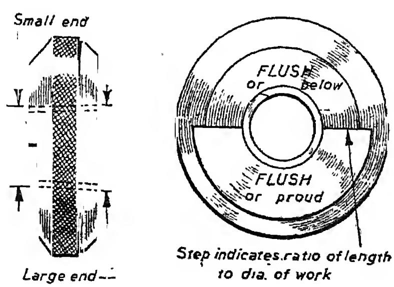


Fig. 43.—Step ring gauge for taper threads such as American national pipe, or Brigg's.

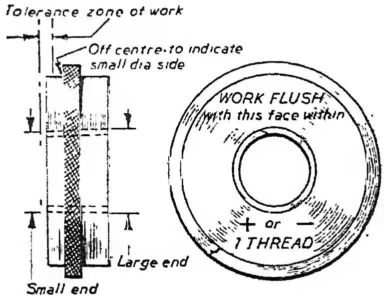


Fig. 44.—Screw ring gauge for taper screws.

When the ring gauge is wound to make contact with the shoulder face, any appreciable error of squareness may be noted by visual examination. The prescribed tolerance of the margin of error is controlled by a slip gauge of predetermined "Go" and "Not Go" limit (Fig. 46).

A typical combination of progressive type of screw ring is shown in Fig. 48. This is of the writer's design, enabling one gauge to check acceptance of thread diameters, length of thread, overall length of bolt, diameter and concentricity and thickness of bolt head. Dowel pins and retaining screws are not shown.

OPTICAL FLATS

Newton's Rings.—The general method adopted for measuring errors of flatness of gauge or precision-finished surfaces is by use of optical flats.

Application of optical flats introduces the basic principle of light wavelength measurement. The process is simple yet affords accurate results. With few exceptions any part that can be measured between flat-gauge contacts can be measured with optical flats.

Fig. 49 illustrates the magnified effect of light-wave interference between gauge block and optical flat surface; note that light reflection from the gauge block interferes with light reflection from the optical flat. This interference sets up wavebands or fringes observed through "flat." The number of and contour of the fringes indicate the error of and curvature of the surface.

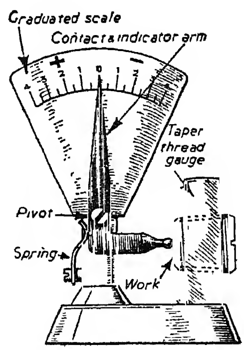


Fig. 45.—Type of gauge for size grading or taper thread screws.

Description.—Optical flats are precision ground and polished discs of very hard crown or optical clear glass or quartz, having no magnifying power. Quartz has not the transparency of glass, but has a much lower thermal coefficient. Care is essential in their use; scratched surfaces do not impair their use as they do not raise a jagged edge, but render observation more difficult.

Accuracy.—The range of uses of optical flats depends upon their accuracy Good-quality flats have truly planed surfaces within 0·000005 in. of dead flat

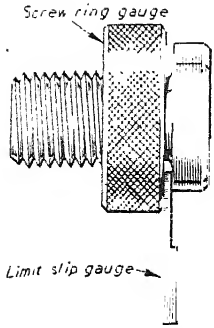


Fig. 46.—Checking squareness of shoulder with thread by inserting slip gauge between shoulder and gauge faces.

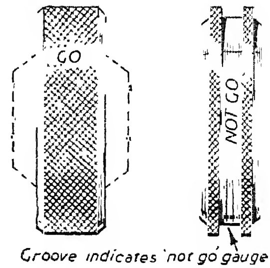


Fig. 48.—Groove to indicate "Not Go" gauge on American threads; the number of grooves also denotes class of fit. The broken line section of "Go" shows recommended practice of additional length of thread, which is more easily ground away when worn.

Master flats are accurately planed within 0·000002 in. to 0·000003 in. (two to three millionths of an inch), and are parallel for thickness within 0·00001 in.

Standard sets contain three flats, termed upper, lower, and reference. Flats may be tested within themselves, in sets of three in the same manner as surface plates are tested for flatness.

Interference Bands.—An example of gauge block flatness checking is shown in Fig. 50. The interference bands are observed through the optical flat, and contour errors of flatness are illustrated in exaggerated sectional view of the gauge block.

When observed in daylight or white light, interference bands appear as rainbow effected fringes. With good-quality flats, measuring constants in daylight are reliable to approximately 0·000012 in. (twelve millionths) per each fringe or band.

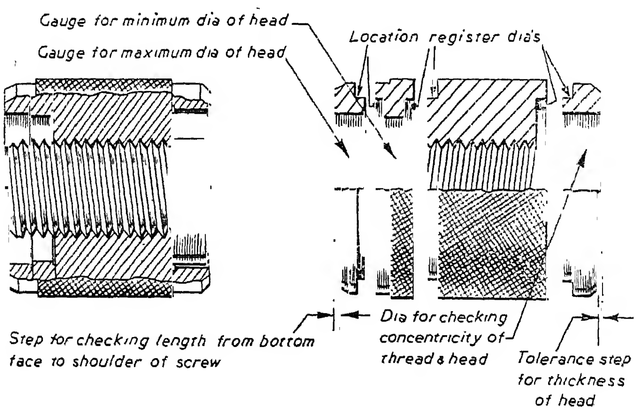


Fig. 47.—Combination gauge for checking length of thread diameter, thickness and concentricity of head with thread, acceptance of thread diameters and overall length.

In precise inspection of these bands, the rainbow coloured effect is filtered, with the result that alternate dark and light bands of one colour-wave appear with a measuring unit of 0·000010 in. Waveband lengths of colours of rainbow range from about 0·000015 in. to 0·000026 in. Colours are filtered by light passing through a selenium glass screen or microscope filter slide. A filter colour of red would pass only the red colour band so that interference bands would appear as alternate red and greyish light waves. The number of bands observed indicate the measurement.

Testing Micrometers.—Optical parallels for use in testing micrometers for planeness, parallelism, and errors in thread pitch are made in sets of three with thickness increments of 0·00625 in. (for 40 t.p.i. thread pitch), which allow of checking at various contact points throughout the 360 degrees rotation of the micrometer spindle.

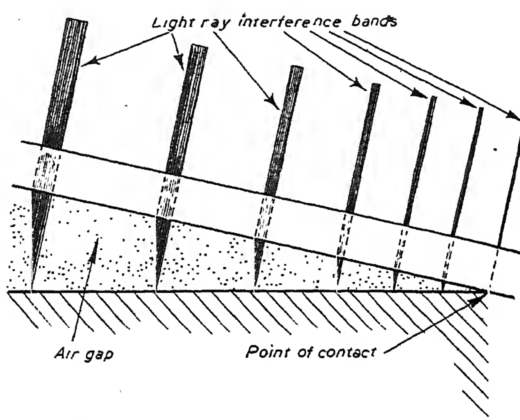


Fig. 49.—Exaggerated action of light-ray interference.

Flatness checking of the micrometer anvil face is shown in Fig. 51. Absence of interference bands when the optical flat is in firm contact prove that the surface is flat. Similar testing of the spindle face is carried out. Parallelism of anvil and spindle faces is carried out by lightly closing the spindle and making contact with optical flat. Presence of out-of-parallel error will be shown by appearance of band around the measuring faces of the micrometer. If four or more bands appear, the micrometer is below standard of accuracy necessary for gauge inspection.

Pitch errors of the micrometer spindle are found by using optical flats as precision parallels in the same manner as slip gauges.

Other Uses for Optical Flats.—Amongst the many uses of optical flats is thread diameter measuring as shown in Fig. 52. This illustration shows the use of a steel reference flat in place of the bottom optical flat. This has the advantage of lower cost and longer life.

Steel references, or toolmakers' flats and toolmakers' precision surface plates, are made in sizes of about 10 in. diameter and lapped plane within 0·00001 in.

Remaining typical uses of optical flats are as follows: Comparing and measuring precision blocks and slip gauges, measuring diameters, lengths, thickness, etc., of

gauges, similarly set up, as shown in Fig. 52; comparing and measuring diameters of thread-measuring cylinders, and testing same for straightness and ovality by rotating cylinders while in contact with optical flats; measuring coefficient of expansion and contraction of materials; measurement of parchment, thickness of small springs and watch movement component diameters, etc.

Optical flats and parts being examined must be scrupulously clean. They should first be washed in alcohol solvent spirit, carefully dried and polished with white chamois leather, and dust or any foreign matter should be lightly removed with a fine camel-hair brush.

Measurement is obtained by the number of interference bands observed from the gauge contact point to the part being measured. The total absence of bands shows that the surface is truly flat. Straight directional bands indicate a plane surface.

Curved bands indicate an out-of-flat surface; if the bands curve away from the contact point the surface is concave.

A convex surface is shown by bands curving around the point of surface contact.

The parts being measured should first be temperature equalised. The time necessary for parts to equalise depends on the size. Approximately 10 minutes for each 1 cu. in. should be allowed.

If the temperature of parts is considerably different before measuring, both the gauge block and work should be placed on a surface plate and parallel or a block placed on top to bridge them, to assist in equalising distributing heat.

Do *not* polish optical flats with paper.

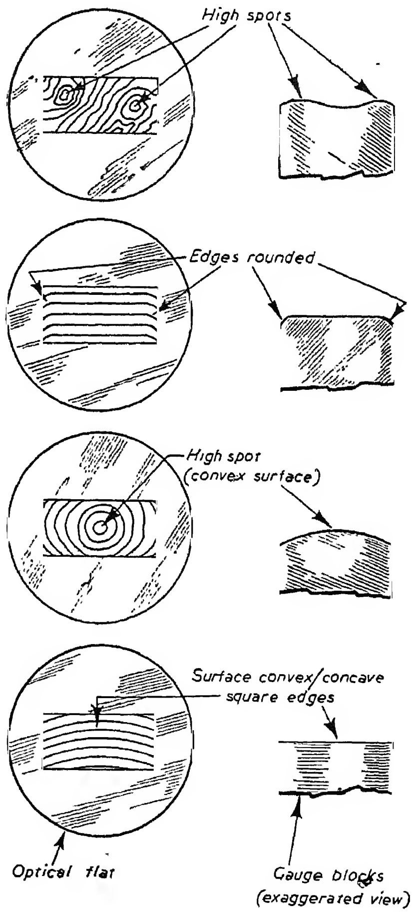


Fig. 50.—Checking surface flatness on slips or gauge blocks.

Other Methods of Flatness Testing.—For less accurate work the surface may be tested with a precision straight edge, which should *not* be a razor edge, as this will soon wear, easily distort, and more easily be damaged than a straight edge with slightly radiused edge.

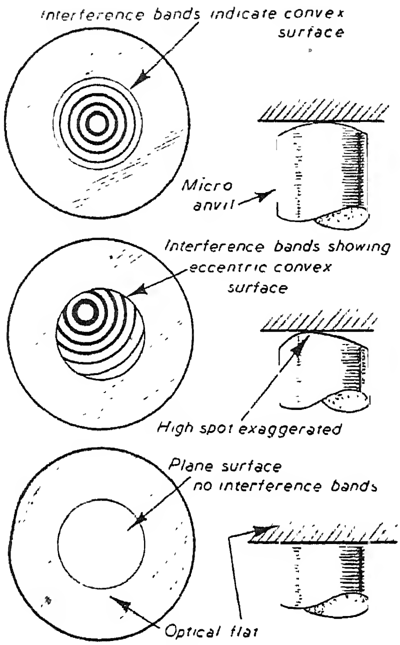


Fig. 51.—Checking flatness of micrometer anvil face.

A straight edge should be of well-seasoned high-grade tool steel, carefully hardened, ground and accurately lapped. Fig. 53 shows a convenient type of straight edge, vented to reduce weight, and provided with a porcelain finger grip to trap the passage of heat from hand to work. A more intense light source is obtained with the addition of a pivoted mirror.

The straight edge may be tested for flatness on a toolmaker's flat. The usual errors are wear, shown by the rounding off of the extreme edges when applied to a flat carefully smeared with uniform film of printers' ink, Prussian blue or red lead, or examined by light gap between straight edge and flat.

Out-of-straightness will be disclosed by rocking to and fro; the straight edge will then appear as concave or convex when tilted towards the user. Tilting in the reverse direction will show an opposite effect of out-of-straight, which proves the straight edge is bent. Any difference in temperature of work and straight edge should be equalised.

An opal, glass-panelled box fitted with a mirror-backed electric bulb may be used to illuminate the gap between the straight edge and the work. Accurate measurement of this gap magnitude is very complicated. As a guide, two perfectly plane knife-edged straight edges will emit a passage of faint blue-tinged light when 0·00002 in.

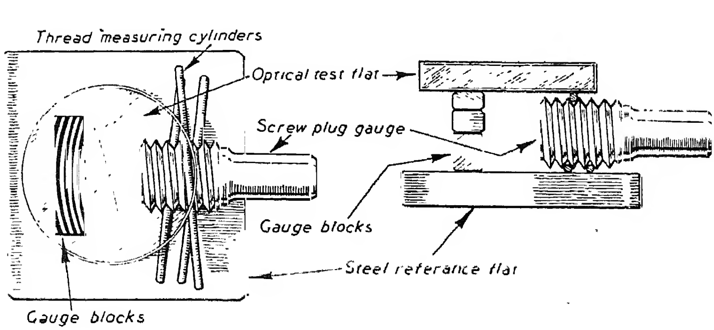
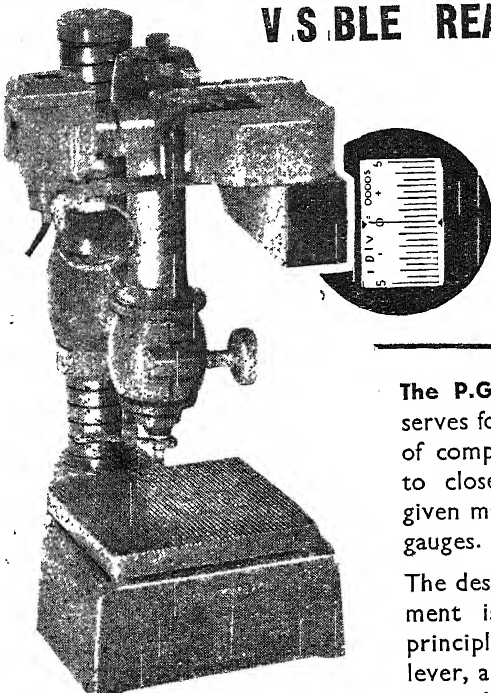


Fig. 52.—Measuring thread effective diameter by light-ray interference.

The Visible COMPAROMETER

VISIBLE READING



PRINCIPAL DIMENSIONS.

HEIGHT OF WORK	8″
RANGE OF SCALE	·002″
GRADUATION OF SCALE	·00005″

The P.G. Comparometer serves for the comparison of components or gauges to close limits with a given master, such as slip gauges.

The design of this instrument is based on the principle of the optical lever, and is projected so that a clear, visible reading is obtained without any strain or effort.

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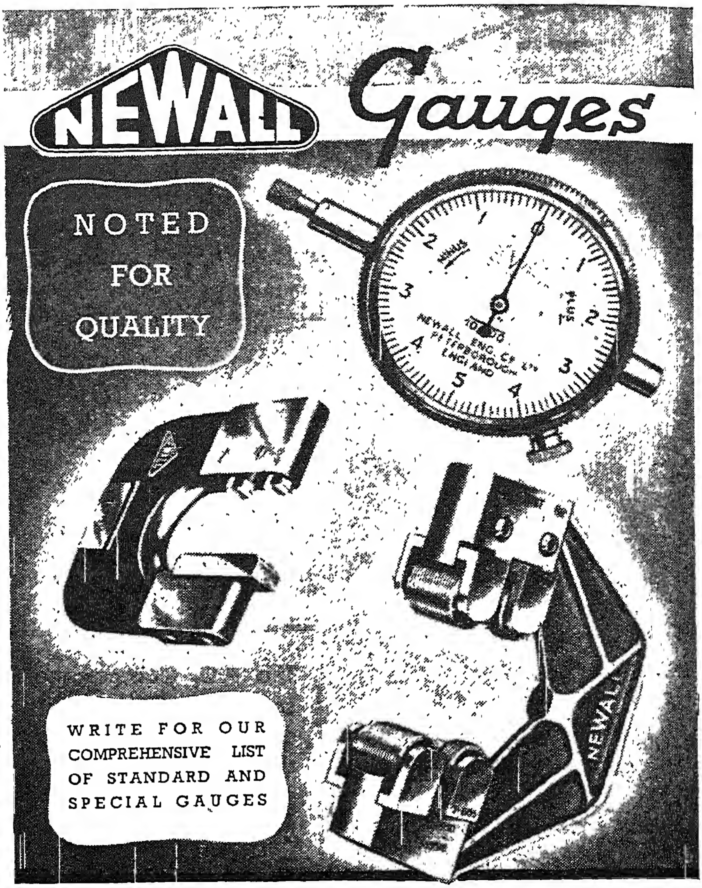
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parallely separated. Blue light remains faint, but changes to greyish-white when straight edges are separated about 0·00004 in. Light gap becomes white and distinct with a gap of 0·0001 in.

Larger gaps may readily be checked by testing with fine feeler blades, gold-leaf parchment, cigarette paper, or thin tinfoil, etc.

Surface Analyser.—While there are quite a number of mechanical and optical instruments for surface examination, a few details of a recent addition are given. The " Tomlinson Surface Analyser " mechanically reproduces surface characteristics, traced on a smoked-glass screen. Vertical movement of the surface contact

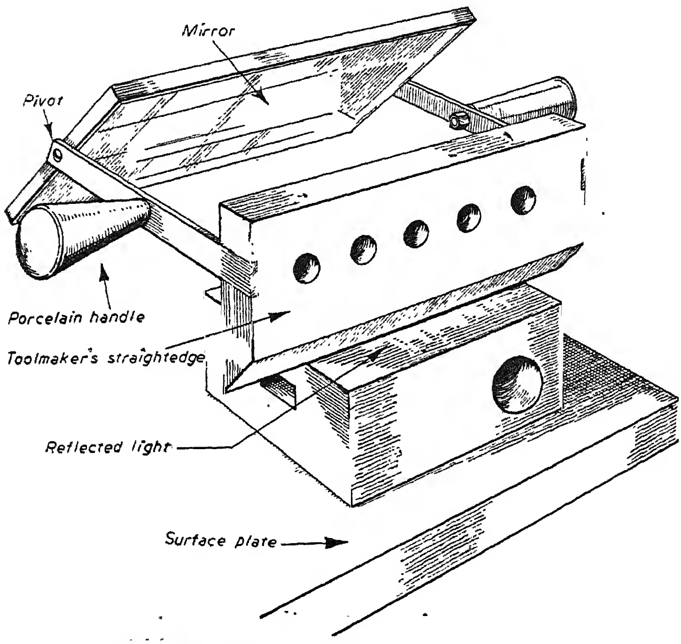


Fig. 53.—Flatness testing with toolmaker's straight edge fitted with mirror.

point is magnified 160 times on a glass screen, horizontal traverse receives no magnification. Further magnification is obtained by the projection of a glass screen at 100 to 1 magnification; giving surface characteristic magnification horizontally 100 times and perpendicularly 1,600 times. A 0·001 in. depression then appears at vertical distance of 16 in.

CONTOUR MEASUREMENT

The measuring of gauges of complex and irregular form is greatly simplified by the use of contour measuring machines and toolmakers' microscopes, which form invaluable equipment of the Gauge Inspection Department.

Outstanding examples of such modern precision measuring apparatus are the Bausch and Lomb contour measuring projector, and the O.M.T. toolmaker's microscope.

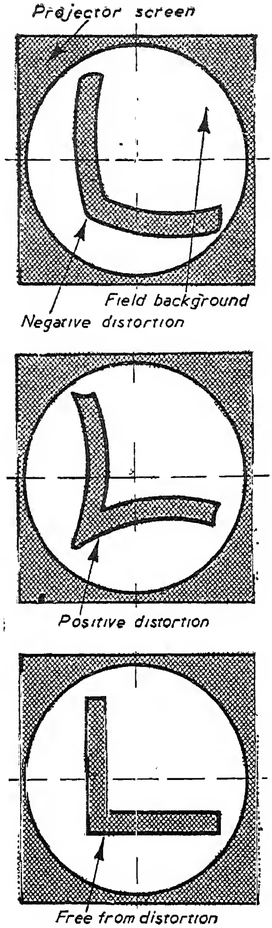


Fig. 54.—Lens distortion and its resulting effect on the projected silhouette of a precision toolmaker's square.

While such equipment has a very wide field of application in both inspection and manufacture, this section will be confined to the aspect of gauge measuring.

Basic Functions.—Briefly, the main features of projection equipment are as follow:

Source of Illumination: This must be sufficiently brilliant to define an image establishing high contrast of the silhouette and working-field background.

Usually, this is effected by the Point-o-Lite or low-voltage coiled tungsten-filament lamp. The light rays pass through the collimation lens which remove colour fringes and maintain parallelism of the beam of light.

The light passes to the work-holding stage provided with accessories such as "centres," vee-blocks, angle brackets, etc. Light passes through the projection lens, and the light-obstruction of the work creates a shadow which is magnified in size. Relation of the focal distance from the work to the screen, together with the projection lens, govern the magnification factor. The optical characteristics decide the margin of distortion within its working field.

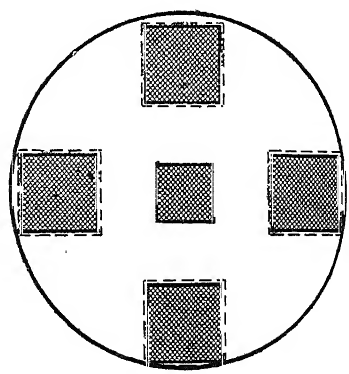


Fig. 55.—Optical distortion, a typical effect.

For precise gauge work, the presence of distortion should be ascertained and results calibrated for future reference to the geometrical truthfulness of a projected contour.

Typical distortion is shown in Fig. 54. The projected image of a precision toolmaker's square is clearly defined, yet has effect of convex or concave sides.

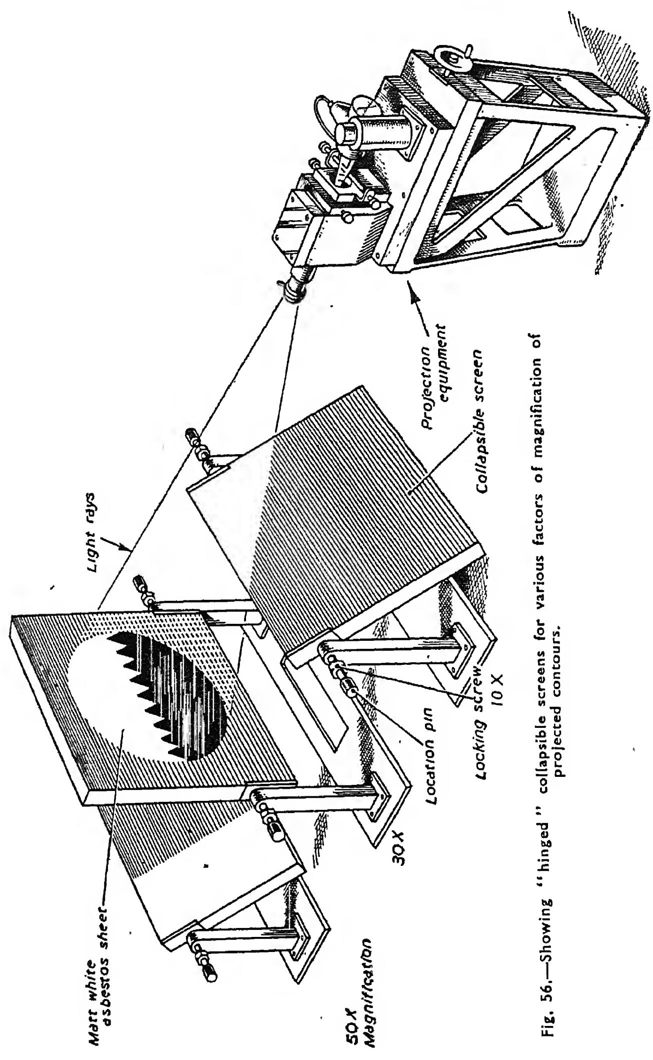


Fig. 56.—Showing "hinged" collapsible screens for various factors of magnification of projected contours.

Such distortion is, perhaps, best described as a varying magnification power of displacement at different positions on the screen, as shown in Fig. 55, and has a varying focal magnification from centre to edge of screen. The illustration shows five precision plates all of exactly similar dimensions and projected at the same time, being positioned at different parts of the work-stage. It will be noted that while the centre plate image is clearly outlined, the remaining plates appear of a larger size and slightly out of focus.

The magnified outline is viewed on a screen, although in the case of the tool-maker's microscope the image may be examined through the eyepiece.

Projected image is shown in its natural aspect, and direction, and not reversed as is the case with the ordinary laboratory microscope.

Horizontal Projector.—The previously named projectors are perhaps the most modern. In practice, it is found that projectors in more general use are of the horizontal large-field type. Magnification is usually 50×, and has the

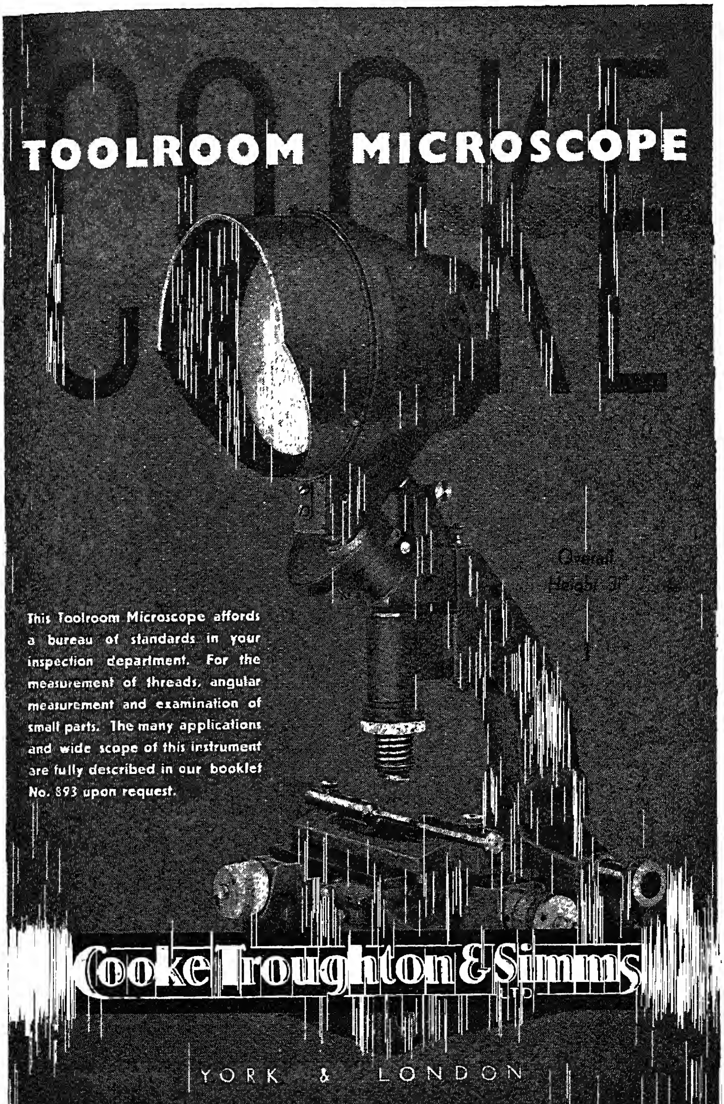
TABLE VIII.—DATA FOR USE IN GAUGE MEASUREMENT BY OPTICAL PROJECTION

British Standard Whitworth					*British Standard Fine*				
Nom. Size (in.)	*Pitch*	*Helix Angle*	*Depth of Thread*	*Basic Eff. Diam.*	*Nom. Size (in.)*	*Pitch*	*Helix Angle*	*Depth of Thread*	*Basic Eff. Diam.*
1/8	0·02500	4° 14′	0·016008	0·1090	3/16	0·031250	3° 24′	0·020010	0·1675
3/16	0·04167	4° 42′	0·026680	0·1608	7/32	0·035714	3° 22′	0·022869	0·1959
1/4	0·05000	4° 10′	0·032016	0·2180	1/4	0·038462	3° 7′	0·024628	0·2254
5/16	0·05556	3° 35′	0·035574	0·2769	9/32	0·038462	2° 43′	0·024628	0·2566
3/8	0·06250	3° 24′	0·040021	0·3350	5/16	0·045455	2° 54′	0·029106	0·2834
7/16	0·07143	3° 19′	0·045737	0·3918	3/8	0·050000	2° 33′	0·032016	0·3430
1/2	0·08333	3° 24′	0·053361	0·4466	7/16	0·055556	2° 21′	0·035574	0·4019
9/16	0·08333	2° 58′	0·053361	0·5091	1/2	0·062500	2° 29′	0·040021	0·4600
5/8	0·09091	2° 55′	0·058212	0·5668	9/16	0·062500	2° 10′	0·040021	0·5255
3/4	0·10000	2° 39′	0·064033	0·6860	5/8	0·071428	2° 14′	0·045737	0·5793
7/8	0·11111	2° 31′	0·071148	0·8039	3/4	0·083333	2° 11′	0·053361	0·6966
1	0·12500	2° 25′	0·080041	0·9200	1	0·100000	1° 56′	0·064033	0·9360

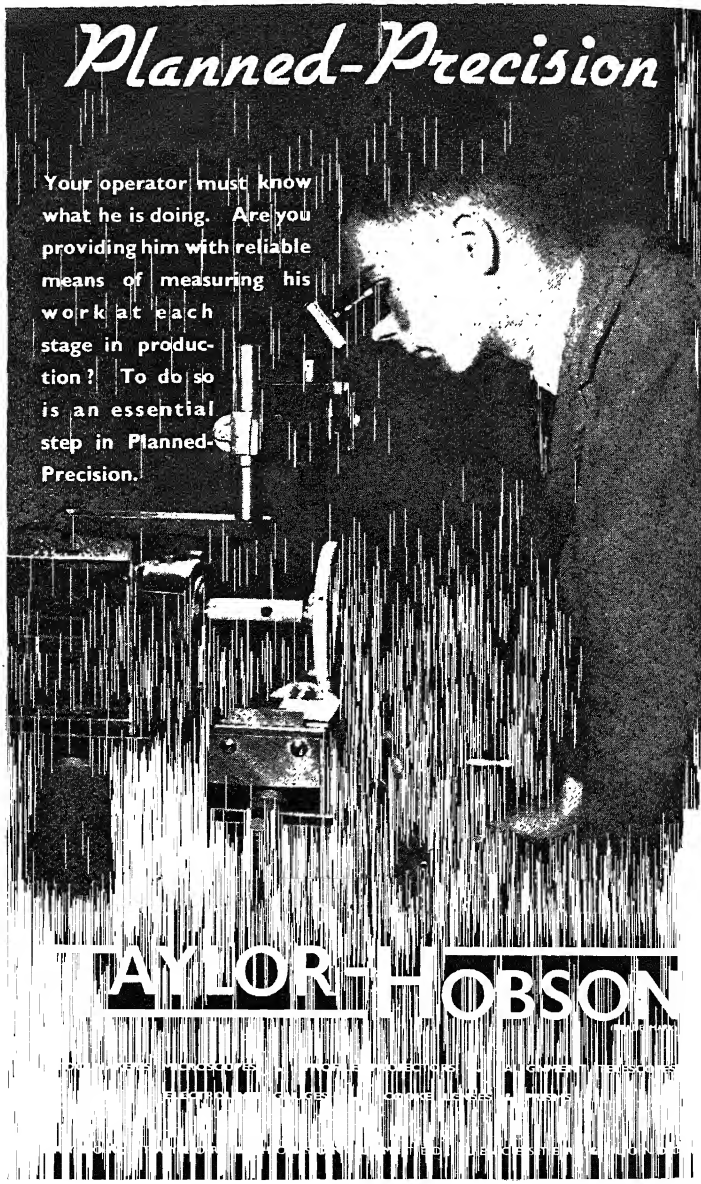
advantage of a working-field of about 6 ft. in diameter, which allows work such as plate gauges, up to about 1¼ in. in size, to be examined as a whole, with full view of the projected complete image.

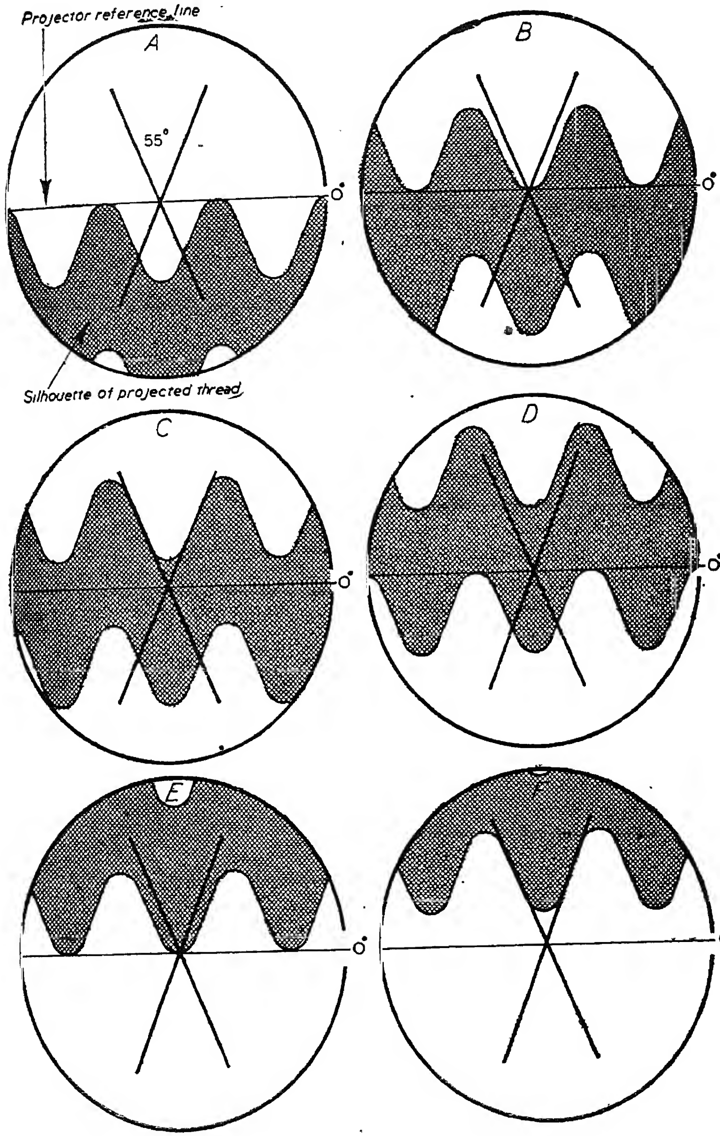
The image is formed on a vertical screen placed about 20 ft. from the projection lens, with focusing cords for remote control of projection adjustment. Later designs incorporate the screen being mounted on flanged wheels which run on rails extending to the projector table, to allow variation of the power of magnification by moving the screen to or from the projection lens, thus correspondingly decreasing or increasing the ratio of magnification.

Operators of the horizontal-type projector may find useful the arrangement shown in Fig. 56, and adopted by the writer, so that varying magnification of 10×, 30× and 50× is instantly obtainable by using appropriate collapsible screen. Location pins, together with locking arrangement, should be provided to ensure that screen is retained vertical.



Pitchfords 2126


Planned-Precision
Your operator must know what he is doing. Are you providing him with reliable means of measuring his work at each stage in production? To do so is an essential step in Planned-Precision.
TAYLOR-HOBSON



Figs. 57 and 58.—Various operations of thread projection.

The setting of the distance is effected by adjustment, so that the measured dimensions of the projected image of a precision cylinder of predetermined diameter equals the cylinder diameter multiplied by the desired magnification factor.

Squareness of the screen may be checked by measuring the projected silhouette at both sides of the screen. If the measurements vary, it proves that the screen is out of square and has to be adjusted until the measurements agree at both sides of the screen. These remarks apply to all types of projectors.

TABLE IX.—DATA FOR USE IN GAUGE MEASUREMENT BY OPTICAL PROJECTION

British Standard Pipe					*British Association*				
B.S.P. Size (in.)	*Pitch*	*Helix Angle*	*Depth of Thread*	*Basic Eff. Diam.*	*No. of B.A.*	*Pitch*	*Helix Angle*	*Depth of Thread*	*Basic Eff. Diam.*
$\frac{1}{8}$	0·035714	1° 49′	0·022869	0·3601	0	0·0394	3° 23′	0·0236	0·2126
$\frac{1}{4}$	0·052632	1° 59′	0·033702	0·4843	1	0·0354	3° 27′	0·0213	0·1874
$\frac{3}{8}$	0·052632	1° 33′	0·033702	0·6233	2	0·0319	3° 30′	0·0191	0·1659
$\frac{1}{2}$	0·071428	1° 40′	0·045737	0·7793	3	0·0287	3° 38′	0·0172	0·1442
$\frac{5}{8}$	0·071428	1° 30′	0·045737	0·8563	4	0·0260	3° 45′	0·0156	0·1261
$\frac{3}{4}$	0·071428	1° 19′	0·045737	0·9953	5	0·0232	3° 46′	0·0139	0·1120
$\frac{7}{8}$	0·071428	1° 9′	0·045737	1·1433	6	0·0209	3° 54′	0·0125	0·0977
1	0·090909	1° 19′	0·058212	1·2508	7	0·0189	3° 57′	0·0112	0·0871
$1\frac{1}{4}$	0·090909	1° 3′	0·058212	1·5918	8	0·0169	4° 2′	0·0102	0·0765
$1\frac{1}{2}$	0·090909	0° 54′	0·058212	1·8238	9	0·0154	4° 16′	0·0092	0·0656
$1\frac{3}{4}$	0·090909	0° 48′	0·058212	2·0578	10	0·0138	4° 17′	0·0083	0·0587
2	0·090909	0° 43′	0·058212	2·2888					

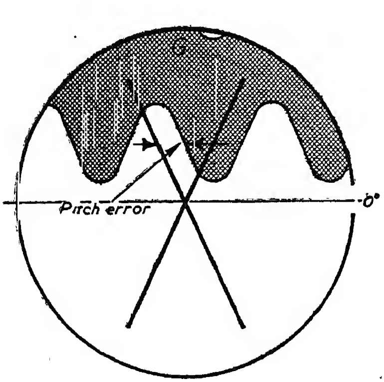


Fig. 59.—The seventh operation in thread measuring by optical projection.

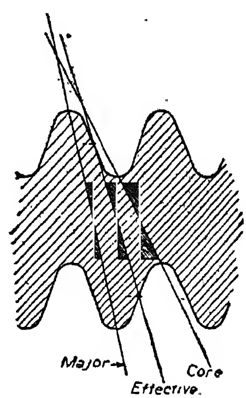


Fig. 60.—Helix angle variation.

TABLE X.—CORRECT LEAD MEASUREMENTS FROM THREAD TO THREAD (IN INCHES)

Number of Threads

No. of T.P.I.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
11	0·09091	0·18182	0·27273	0·36364	0·45455	0·54546	0·63637	0·72728	0·81819	0·90901	1·000	—	—	—
12	0·08333	0·16667	0·25000	0·33333	0·41667	0·5000	0·58333	0·66667	0·75000	0·83333	0·91667	1·000	—	—
14	0·07143	0·14286	0·21429	0·28572	0·35715	0·42858	0·5000	0·57143	0·64286	0·71430	0·78573	0·85713	0·92858	1·000
16	0·06250	0·12500	0·18750	0·25000	0·31250	0·37500	0·43750	0·5000	0·56250	0·62500	0·68750	0·75000	0·81250	0·87500
18	0·0556	0·11111	0·16668	0·22222	0·27778	0·33330	0·38888	0·44444	0·5000	0·55556	0·61106	0·66667	0·72218	0·77779
19	0·05263	0·10526	0·15789	0·21052	0·26315	0·31578	0·36841	0·42104	0·47367	0·52630	0·57893	0·63156	0·68419	0·73682
20	0·05	0·1	0·15	0·2	0·25	0·3	0·35	0·4	0·45	0·5	0·55	0·6	0·65	0·7
22	0·04546	0·09091	0·13637	0·18184	0·22730	0·27276	0·31822	0·36368	0·40914	0·45460	0·5000	0·54546	0·59091	0·63637
26	0·03846	0·07692	0·11538	0·15384	0·19230	0·23076	0·26922	0·30768	0·34714	0·38460	0·42306	0·46152	0·5000	0·53846
32	0·03125	0·06250	0·09375	0·12500	0·15625	0·18750	0·21875	0·25000	0·28125	0·31250	0·34375	0·37500	0·40625	0·43750
40	0·0250	0·050	0·075	0·10	0·125	0·150	0·175	0·20	0·225	0·250	0·275	0·30	0·325	0·350

Thread Measuring.—Operational sequence usually adopted is illustrated in Figs. 57 to 59, and the degree of accuracy associated with measuring by optical projection is given overleaf. It may be stated that more accurate results are attained ; however, the values given were found to represent the mean results of various operators.

Pitch and lead within 0·0001 in.
Angular measurements to 2 minutes of arc.
The " tilt " of thread within 3 minutes of arc.
Major and minor diameters within 0·0001 in.
Effective diameter to 0·0001 in.

Reverting to A of Fig. 59, there is shown a horizontal reference line in true coincidence with the outline of the projected thread crest radii. The dimension, as registered by the micrometer actuating the work-holding stage, is assumed equal to 0·7922 in. In diagram B the thread, being " projected," has traversed until reference line now coincides with thread root radii.

To focus root radii to define a sharp outline, the work has to approach the beam of light parallel to the helix angle of the thread root diameter. With threads of less than 5 degrees helix angle, it is customary to set the helical index equivalent to the pitch diameter helix when the pitch is equal to the lead.

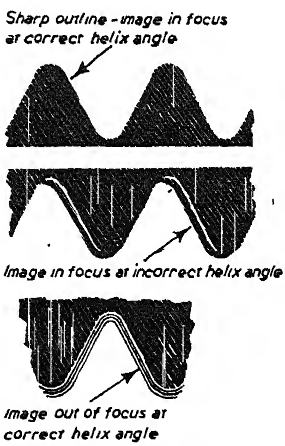


Fig. 61.—Effect of image viewed at correct and incorrect helical and focal setting.

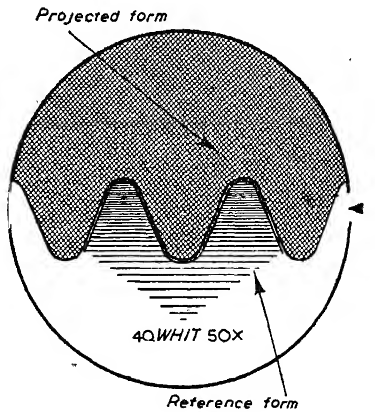


Fig. 62.—Comparing "projected" and "reference" form of thread.

Fig. 60 shows helical variation relative to individual diameters for the gauge in question. Precise focal truthfulness is best obtained by inspection of the silhouette at various angles of approach of light and work determined by margin of difference between helices of root and crest diameter.

The helix angle of pitch diameter is calculable thus :

$$\text{Tan helix angle} = \frac{\text{Lead of thread}}{3{\cdot}1416 \times \text{pitch diameter}}.$$

Tables VIII and IX have been compiled to give helix angles for all standardised threads generally used.

Required helix is found in the B.S.F. section of Table VIII, viz. 2° 29′, so that index is adjusted to corresponding reading.

As a considerable number of " shadowgraph " machines are not equipped with

TABLE XI.—CORRECT LEAD MEASUREMENTS FROM THREAD TO THREAD FOR BRITISH ASSOCIATION THREAD (IN INCHES)

B.A. No.	*Number of Threads*									
	1	2	3	4	5	6	7	8	9	10
0	0·03937	0·07874	0·11811	0·15748	0·19685	0·23622	0·27559	0·31496	0·35433	0·39370
1	0·03543	0·07087	0·10630	0·14173	0·17717	0·21260	0·24803	0·28346	0·31890	0·35433
2	0·03189	0·06378	0·09567	0·12756	0·15945	0·19134	0·22323	0·25512	0·28701	0·31890
3	0·02874	0·05748	0·08622	0·11496	0·14370	0·17244	0·20118	0·22992	0·25866	0·28740
4	0·02598	0·05197	0·07795	0·10394	0·12992	0·15591	0·18189	0·20787	0·23386	0·25984
5	0·02323	0·04646	0·06969	0·09291	0·11614	0·13937	0·16260	0·18583	0·20906	0·23228
6	0·02087	0·04173	0·06260	0·08346	0·10433	0·12520	0·14606	0·16693	0·18780	0·20866
7	0·01890	0·03780	0·05669	0·07559	0·09449	0·11339	0·13228	0·15118	0·17008	0·18898
8	0·01693	0·03386	0·05079	0·06772	0·08465	0·10157	0·11850	0·13543	0·15236	0·16929
10	0·01378	0·02756	0·04134	0·05512	0·06890	0·08268	0·09646	0·11024	0·12402	0·13779

means of indicating helix settings, the method illustrated in Fig. 61 is applied. When image is focused at correct helix arrangement the outline of projected image is sharp and clearly defined. Adjusting the shadow slightly out of focus, discloses fringes and reflected light of equal density and cross-section forming along image perimeter, and proves absence of thread interference; therefore, when no helix index is provided, the projected contour is set slightly out of focus, and the "rake" of light, or work, is positioned so that reflected light appears of equal volume.

Visual effects of projection at incorrect helix is also seen in Fig. 61.

Reverting to view B of Fig. 59; it is assumed that the dimension indicated by micrometer graduations, when the reference line agrees with root radii outline, is 0·7520 in.

The 55-degree angular reference lines are in "optical contact" with thread flanks shown in diagram C, and we accept measurement as given by micrometer reading of 0·7322 in.

To focus the diametrically opposed threads, the helical setting is reversed.

The work image traverses the screen until the horizontal reference line coincides with root radii as in D. The micrometer dimension registers 0·3322 in. The work stage is moved to match-up the horizontal reference line with summit of thread crest radii, view E. Assume the micrometer reading equals 0·2920 in. Finally, for diametral measuring, the angular reference lines are brought into coincidence with flanks of thread as illustrated in F of Fig. 59, whereupon we take for granted that the micrometer scale indicates 0·2720 in.

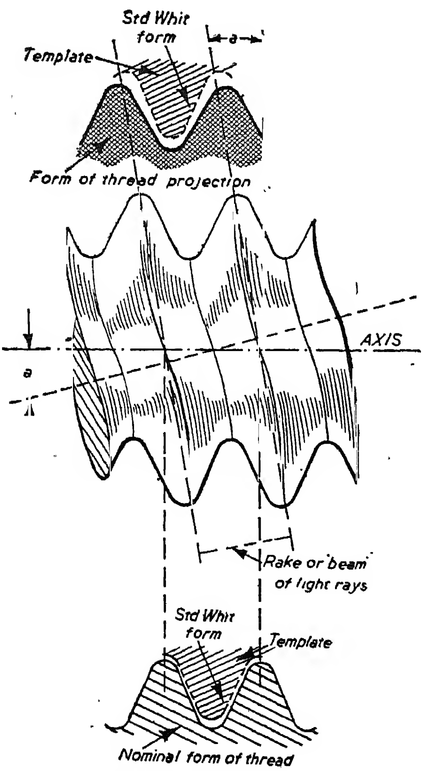


Fig. 63.—Showing difference in "actual" and "projected" form of thread.

Pitch Measuring.— Whilst the work is positioned as at F, the pitch dimension is determined. Firstly, we assume for clarity that the longitudinal micrometer reading is 0·4315 in., rotating the micrometer drum to alter the position of work-stage and match up silhouette of adjacent thread profile with the angular reference lines, noting micrometer reading, e.g. 0·4940 in.; thus the difference indicates a measured distance of one thread pitch, i.e. 0·4940 in. — 0·4315 in. = 0·0625 in.

Again referring to Table VIII, we note that the correct pitch dimension is 0·0625 in.

Table X would be used for measuring adjacent and consecutive threads, the measured dimension obtained being compared with the tabulated value corresponding to the number of pitches measured. In use, the tables will be found very useful

TABLE XII.—CORRECT LEAD MEASUREMENTS FROM THREAD TO THREAD FOR METRIC THREAD (IN INCHES)

Number of Threads

Mm. Pitch	1	2	3	4	5	6	7	8	9	10	11	12
0·25	0·00984	0·01969	0·02952	0·03937	0·04921	0·05906	0·06890	0·07874	0·08859	0·09843	0·10827	0·11811
0·50	0·01969	0·03937	0·05906	0·07874	0·09843	0·11811	0·13780	0·15748	0·17717	0·19685	0·21654	0·23622
0·75	0·02953	0·05906	0·08858	0·11811	0·14764	0·17717	0·20669	0·23622	0·26575	0·29528	0·32480	0·35433
1 mm.	0·03937	0·07874	0·11811	0·15748	0·19685	0·23622	0·27559	0·31496	0·35433	0·39370	0·43307	0·47244
1·25	0·04921	0·09843	0·14764	0·19685	0·24606	0·29528	0·34449	0·39370	0·44291	0·49213	0·54134	0·59055
1·50	0·05906	0·11811	0·17717	0·23622	0·29528	0·35433	0·41339	0·47244	0·53150	0·59055	0·64961	0·70866
1·75	0·06890	0·13780	0·20669	0·27559	0·34449	0·41339	0·48228	0·55118	0·62008	0·68898	0·75788	0·82677
2 mm.	0·07874	0·15748	0·23622	0·31496	0·39370	0·47244	0·55118	0·62992	0·70866	0·78740	0·86614	0·94488
2·5	0·09843	0·19865	0·29528	0·39370	0·49213	0·59055	0·68898	0·78740	0·88583	0·98425	1·08268	1·18111
3 mm.	0·11811	0·23622	0·35433	0·47244	0·59055	0·70866	0·82677	0·94488	1·06299	1·18110	1·29921	1·41732
4 mm.	0·15748	0·31496	0·47244	0·62992	0·78740	0·94488	1·10236	1·25984	1·41732	1·57480	1·73228	1·98976

and time-saving, indicating directly pitch measurement up to 14 consecutive threads. Tables XI and XII are similarly compiled for British Association and Metric series respectively.

The presence of pitch error would appear as in view G of Fig. 59.

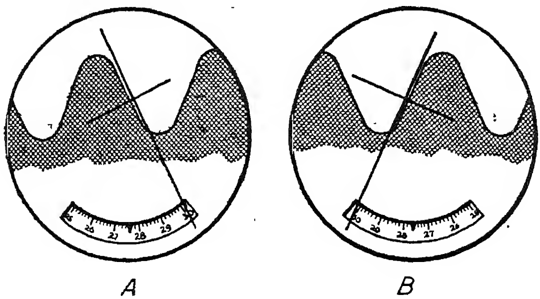


Fig. 64.—Measuring flank angle of projected thread profile.

Form Measurement.—The projected form of thread is compared with the reference contour as illustrated in Fig. 62, and which would disclose size errors of radii or imperfect blending with flanks.

For precise gauge work, however, the angle of the thread has to be measured separately, due to the fact that, assuming the angular profile of the gauge being examined is precisely 55 degrees, it would show an angular error in comparison

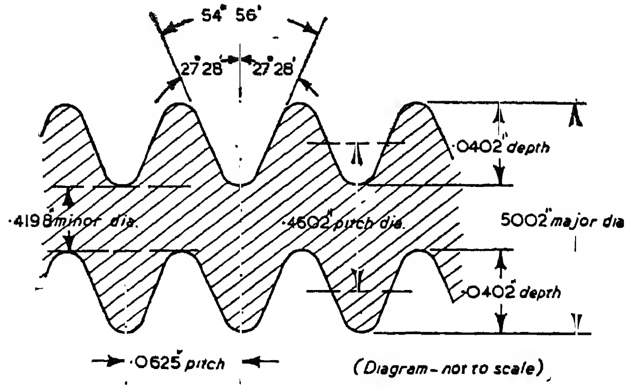
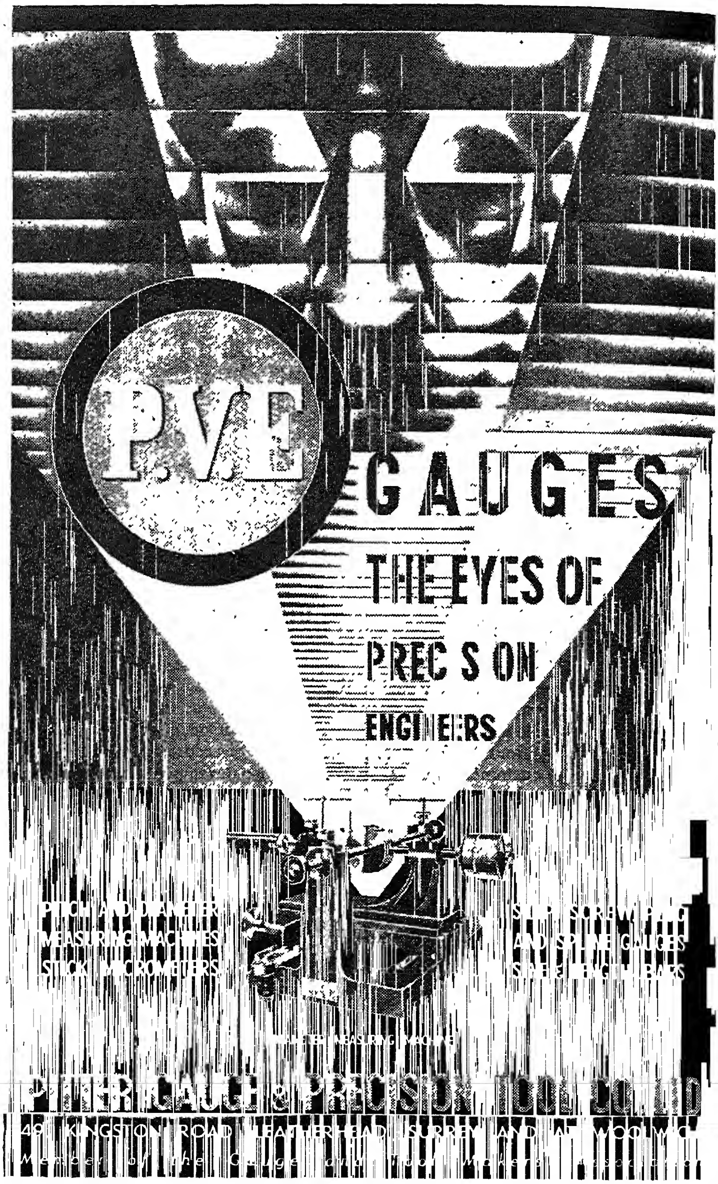


Fig. 65.—Summary of measurement of screw plug gauge, by optical projection method.

with the reference angle which is also precisely 55 degrees. Fig. 63 proves light rays do not project a cross-section in the axial plane of the gauge thread, but project an image of a true cross-section perpendicular to the helix.

It is apparent, therefore, that to check the angle of thread accurately in comparison with a reference profile entails a reference profile for each individual thread contour, governed by the diameter and helix.


P.V.E
GAUGES
THE EYES OF
PREC S ON
ENGI EERS
PITCH AND DIAMETER
MEASURING MACHINES
STICK MICROMETERS

A correction has to be allowed for this angular discrepancy and calculated from the formula:

$$\text{Cot } A = \text{Cot } B \times \cos C.$$

where A = Corrected flank angle.
B = Normal flank angle.
C = Helix angle at pitch diameter.

From Fig. 63 it is evident that the projected angle will be more acute than the actual thread angle, and therefore the value of correction will be additive to each flank angle as measured.

With shadowgraphic examination of male threads of smaller helix than 2 degrees the correction factor may be dispensed with, but it is strictly dependent upon required accuracy.

Typical angle measurement is depicted in Fig. 64, A view indicating a flank angle of 27° 27′, as also in the flank angle measurement shown in B. It is noted that both flank angles are of similar inclination, thus denoting thread free from "tilt." If, for example, there was a variance of 5′ between the angular measurement, then the thread would be termed as having a 5′ "tilt," or what is sometimes titled as "lean."

For gauge in example, we formulate the correction from which we derive 1′ added to 27° 27′, which gives a true angle of 27° 28′.

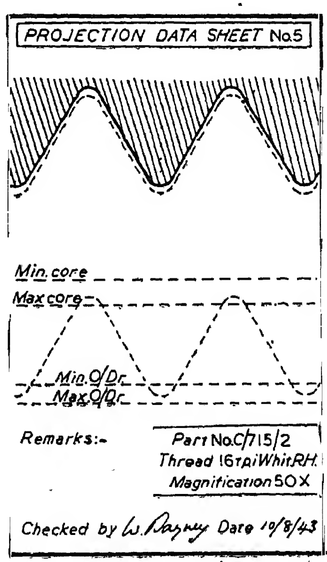


Fig. 66.—Typical repetition projection check sheet. Broken lines indicate work.

Summary of Measured Dimensions.—From the foregoing evaluate their various elements. The result shown in Fig. 65 is determined as below; the letters A, B, etc., refer to the view so indicated in Fig. 6.

Major diameter = A − E = 0·7922 in. − 0·2920 in.
Major diameter ∴ = 0·5002 in.
Pitch diameter = C − F = 0·7322 in. − 0·2720 in.
Pitch diameter = 0·4602 in.
Minor diameter = B − D = 0·7520 in. − 0·3322 in. = 0·4198 in.
Depth of thread = A − B = 0·7922 in. − 0·7520 in. = 0·0402 in. or D − E = 0·0402 in.
Flank angles = 27° 27′ + correction value of 1′.
Flank angles = 27° 28′.

Typical Applications.—A few of the applications of shadowgraphic examination are given below: measuring of:

Pressure angle, clearance and meshing effect of gears.

Contour of forming tools, sealing rolls, cams, punches and dies, and exceptionally small pressed-work, such as watch and clock movement components and assemblies.

Pitch, lead and form of hobs, chasers, taps, broaches, splines, and serrations.

Jigs and fixtures, castings, etc.

There being a total absence of contact pressure, it is frequently found that optical projection is the only means of accurately measuring fragile or soft work parts, such as coiled filaments, rubber and similar materials.

Use of photographic screen and accessories enables permanently accurate records being available, of sample products for future reference or as conclusive information for personnel not immediately at hand.

It is unreliable to state any fixed rules for exposure time, and best results are obtained by trial.

Shrinkage and distortion of films and paper usually result in ambiguous replicas. For accuracy, it is advisable to use a glass plate which will, of course, be a negative image, the light field background appearing dark, whilst the contour shadow is shown as light, and in reverse aspect to that shown on the projector screen.

Excessive surface brightness of the work may be eliminated by carefully "smoking" over ignited paraffin; conversely, to increase the surface reflective power, the work is held in close proximity to burning magnesium ribbon.

Care is essential in focusing of the silhouette and also to ensure that the work is positioned to appear central on the exposed photo-plate.

Reference Charts.—For the repetition inspection of small male threads, data sheets such as shown in Fig. 66 are used. The enlarged thread form is drawn at the top of the chart, and maximum and minimum diameter index lines drawn

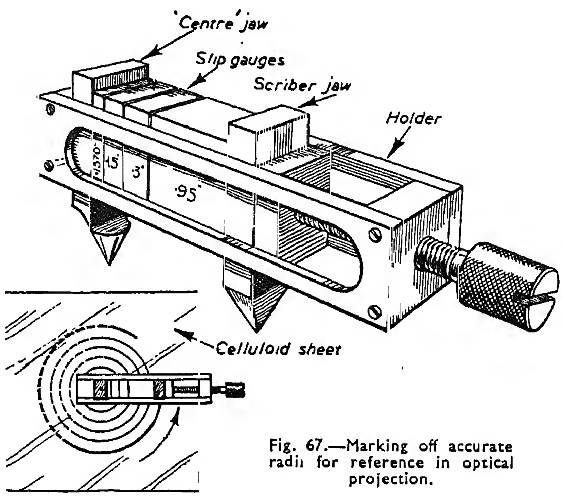


Fig. 67.—Marking off accurate radii for reference in optical projection.

at the bottom. In use, the work is focused and positioned to coincide with "effective zone" of contour on the chart, which is attached to the screen.

On screens, as used with the horizontal-type projector, the chart should be attached thereon with adhesive tape to avoid the well-established error of a pin-perforated screen.

Observing the position of the image of opposite crest and root radii in relation to tolerance lines at the bottom of chart, will show whether the work is of correct diametral size.

Maximum diameter of work capable of being checked in this manner will depend upon the largest diameter accommodated within the working-field capacity of screen.

Fig. 67 shows construction of radii on sheet celluloid for comparative measuring of a projected radius. Use of slip gauges and holder with male centre and scriber jaw give accurate results: similar reference plates may be made of glass plate, using tungsten carbide-tipped scriber point. The lines may afterwards be blacked-in with Indian ink or a waxed pad.

Profile Gauge Measuring.—A simple example of optical measuring of a plate gauge is shown in Fig. 68, together with alphabetical sequence of checking.

Prior to projection, it should be ascertained that the gauging surface is reasonably square, and plane; out-of-squareness would result in an ambiguous silhouette, as also being difficult of focusing to a sharp outline.

Too high a magnification power causes serious falling off of light intensity. It will generally be found that 25 × is ample. Light intensity may be increased when required by inserting a magnifying lens between the collimator and projector lens.

Direct measurement of internal thread form, pitch, and diameters introduces serious difficulty, in particular the " proof of contact pressure."

The measuring and checking of screw ring gauges of less than ⅜ in. thread diameter is usually confined to the use of test or check plugs, of which mention has previously been made in this series. Provided that the thread form and pitch are correct, the latter method is satisfactory and is standard practice both in this country and America. For the smaller series of threads such as the B.A., it is the only method available.

Examination of Thread Form.—The use of test plugs does not take rounding at the crest and root into complete account, and it therefore becomes necessary to examine the thread form. Direct contour projection being impossible, the examination is carried out with a cast of the thread.

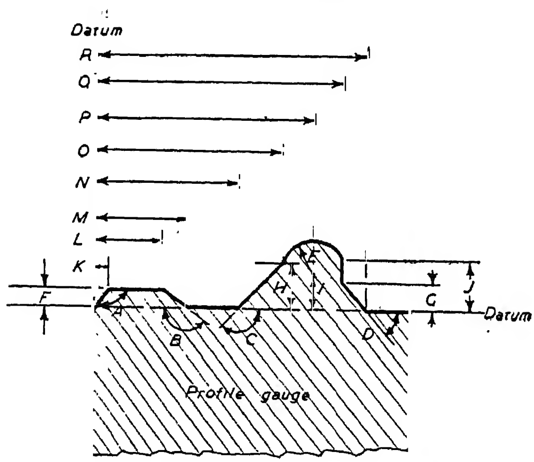


Fig. 68.—Measuring profile gauge by optical projection.

The cast is obtained by holding the gauge in blocks, or between vice jaws as shown in Fig. 69. The cast segment should be less than half-gauge thread diameter, to avoid screwing out the cast.

This cast is then examined and measured on optical projection apparatus or a toolmaker's microscope, for convenience in mounting; Plasticine will be found useful. The flank and form angles are measured, and the results noted for use in determining gauge effective diameter. Concentricity of thread diameters is checked, and for this purpose two or more casts should be obtained at various parts along the thread circumference.

Measuring Pitch of Thread.—With the use of the pitch-measuring machine, the screw ring is held on a face-plate or in a chuck as shown in Fig. 70. The stylus appropriate to the form and pitch of thread being examined is selected and assembled with an auxiliary bar mounted in engagement with the indicator. The measurement of pitch is carried out similarly to screw-plug checking.

To allow for any discrepancies of alignment of gauge with the machine axis, two sets of readings should be obtained by measuring after the gauge has been rotated

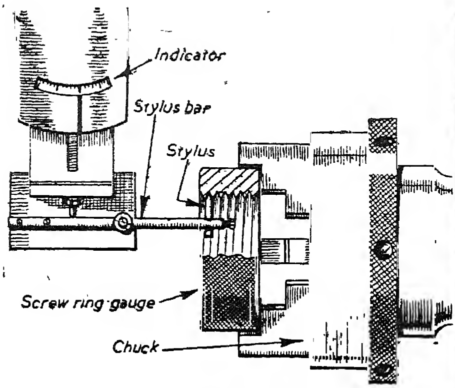


Fig. 70.—Pitch measuring of screw ring gauge.

180 degrees through its own axis, and from its first position. From the mean of the results so obtained comparison with the pitch reference graph will indicate the actual desired measurement.

Measuring Apparatus.—A simple type of appliance for measuring the effective diameter is shown in Fig. 71, which is an adjustable length-bar with spherical contact faces and provided with a locking ring.

Obvious disadvantages are that when locked in position with the thread flanks of the ring gauge, the length-bar has to be screwed-out in addition to there being no control of contact pressure. The range of threads that can be measured with any distinct degree of accuracy is limited to rather coarse thread pitch and large diameters. Measuring is awkward on sizes smaller than 1 in., and requires great manipulative dexterity with the use of tweezers, etc. It must be noted that in determining the overall length for checking the thread diameter, allowance must be made for helical tilting of the length-bar which depends upon the pitch of the thread being measured. In practice, it is rarely found practicable to use this method on threads finer than 18 t.p.i., due to the size of the ball ends having to be smaller than about $\frac{1}{32}$ in. diameter.

Internal Thread Micrometers.—Fig. 72 shows the adaptation of a standard type of inside micrometer for measuring the effective thread diameters from 2 in. to upwards of 12 in. diameter with the use of tubular extension bars.

Interchangeable thread anvils allow for the range of threads as follow :

Set of anvils No.	1	=	$4\frac{1}{2}$ to 7 t.p.i.
,, ,,	2	=	8 to 13 ,,
,, ,,	3	=	14 to 20 ,,
,, ,,	4	=	22 to 30 ,,
,, ,,	5	=	32 to 40 ,,

An expanding-jaw type of micrometer is shown in Fig. 73.

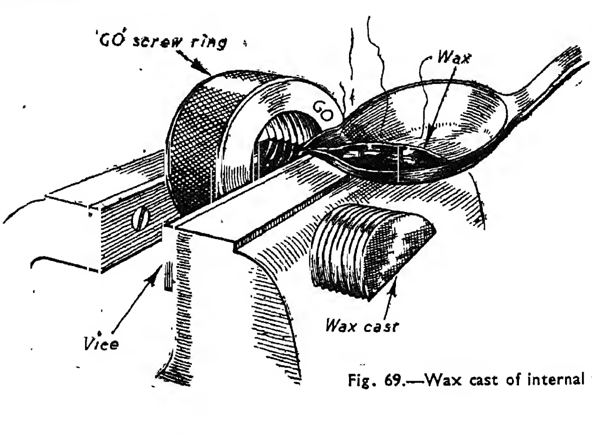


Fig. 69.—Wax cast of internal thread.

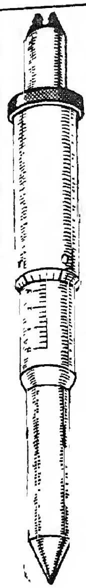


Fig. 72.—Internal thread micrometer.

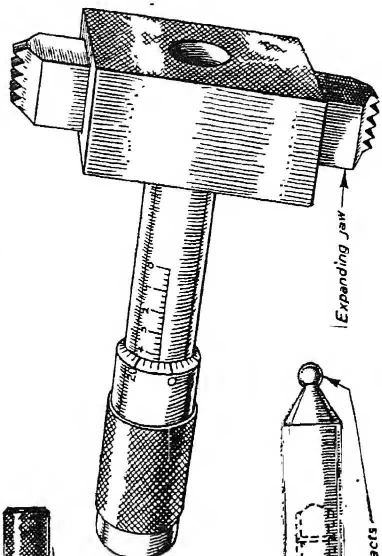


Fig. 73.—Expanding-jaw type of internal thread micrometer.

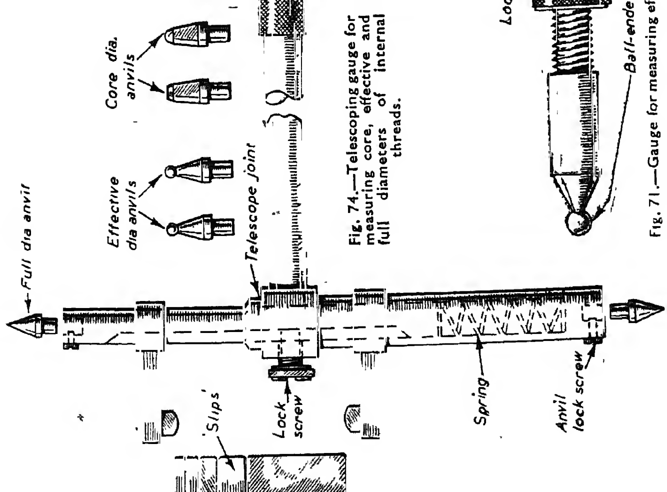


Fig. 74.—Telescoping gauge for measuring core, effective and full diameters of internal threads.

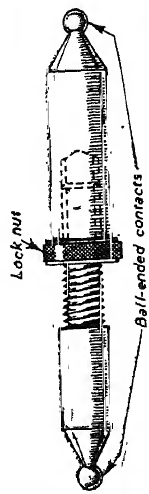


Fig. 71.—Gauge for measuring effective diameter of female threads.

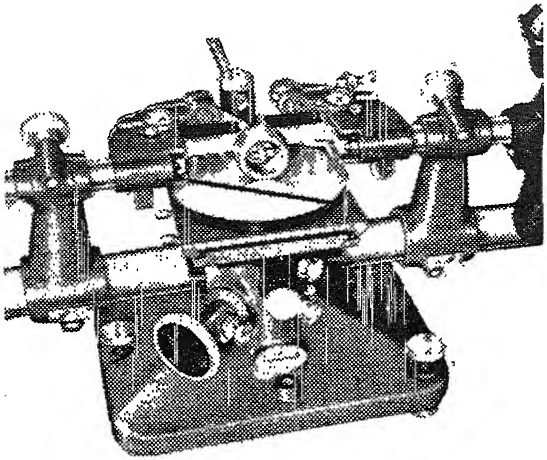


Fig. 75.—The O.M.T. Omtimeter, shown as set for measuring internal threads.

The jaws make contact with an inclined surface at the end of the micrometer spindle so that the rotation of the micrometer spindle causes a linear movement of the jaws, which, in effect, varies the diameter of the thread. Such a gauge is perhaps most useful for checking the ovality and rate of taper.

Telescoping Gauge.—A convenient gauge for both comparative checking and measuring of individual internal thread diameters is illustrated in Fig. 74.

The contact arms, with one spherical and one flat gauging surface, allow of accuracy being obtained in measured results, and a setting process, by use of slip or block gauges.

Various interchangeable anvils allow checking of full, effective and core diameters as separate items. A worth-while addition would be a male and female thread anvil as used on the internal thread micrometer (Fig. 72). This would allow direct effective diameter measurement without compensation, allowing for helical tilting, which is otherwise essential.

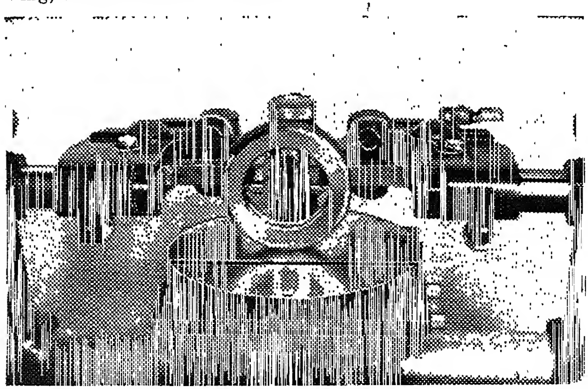


Fig. 76.—Close-up view of Omtimeter method of measuring screw ring gauge.

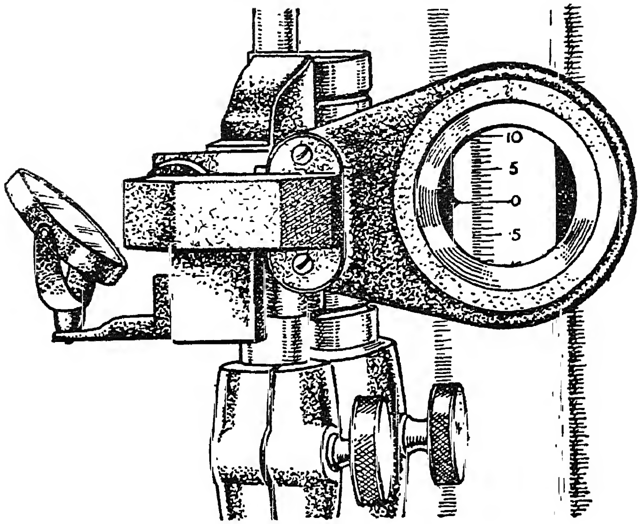


Fig. 77.—Projection attachment.

The contact pressure is reasonably controlled by means of an incorporated compression spring (see Fig. 74). With the use of various ball-contacts, the

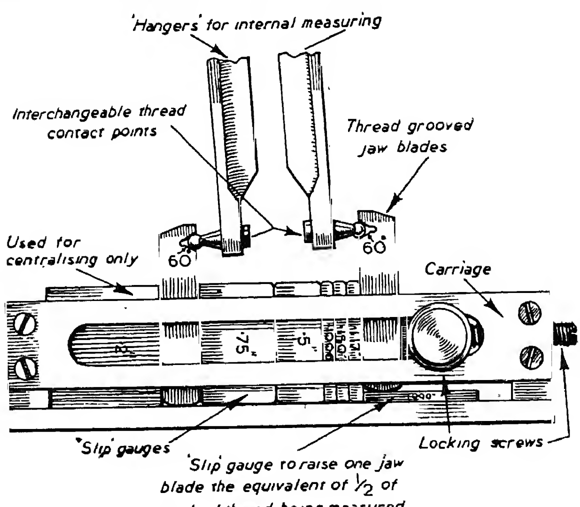


Fig. 78.—Setting arrangement for comparative checking of internal thread diameters.

range of threads from 6 t.p.i. to 40 t.p.i. may be checked. Diameters from 1 in. to 6 in. are accommodated with varying lengths of telescope arm.

Precision in Thread Measuring.—A recent development in the field of internal thread measurement introduces the O.M.T. Omtimeter, which is a British-made optical-mechanical precision instrument for the external and internal measuring of plain or threaded work. While the range of this instrument is very great indeed, the remarks in this section will be confined to its application in measuring internal threads.

The general view of the Omtimeter is shown in Fig. 75. A close-up view of the set-up is shown in Fig. 76.

Briefly, the internal measuring equipment comprises two hangers clamped to the headstock and the tailstock respectively. The prongs of these hangers are fitted with interchangeable anvils for thread contact with the gauge being examined. The headstock carries the Omtimeter tube indicator unit.

The contact pressure of about 8 oz. is constant and beyond the influence of the operator.

The optical magnification is in the region of 1,000 to 1, so that variations of 0·001 in. appear as 1 in. Furthermore, the use of the interesting projection attachment, Fig. 77, permits the reading of such scale graduations at normal reading distance, so that several persons may observe the results simultaneously.

Setting Operation.—The ball-end anvils selected for the thread being measured are fitted to hanger prongs. A composite internal thread reference gauge is built up with a pair of opposed vee-grooved jaw blades, between which are inserted slip gauges corresponding to the gauge nominal effective diameter, minus the virtual effective dimension of jaw blades.

Compensation is made for helical tilting by raising one jaw blade to a plane higher than the other jaw blade, equivalent to one-half the pitch of thread, and is retained in this position by the slip gauge under the base of the raised jaw blade. This assembly is held in a carriage, as shown in Fig. 78.

This carriage is mounted on a work-holding table, the anvils are positioned in vee-grooves and the graduated scale adjusted to indicate a zero reading. By depressing the hangers the carriage is removed, and a gauge takes its place. The dimensional variation of the actual and nominal effective diameter is directly indicated. It will, of course, be appreciated that the effective diameter dimension so obtained relates to the simple, as distinct from the virtual, effective.

With the use of different contact anvils the process is similar for measuring the full and core diameters.

As 0·00005 in. contact plunger deflections appear as 0·05 in., it follows that estimations may readily be made of units of 0·000025 in. The accuracy of results largely depends upon the accuracy of the slip gauges used.

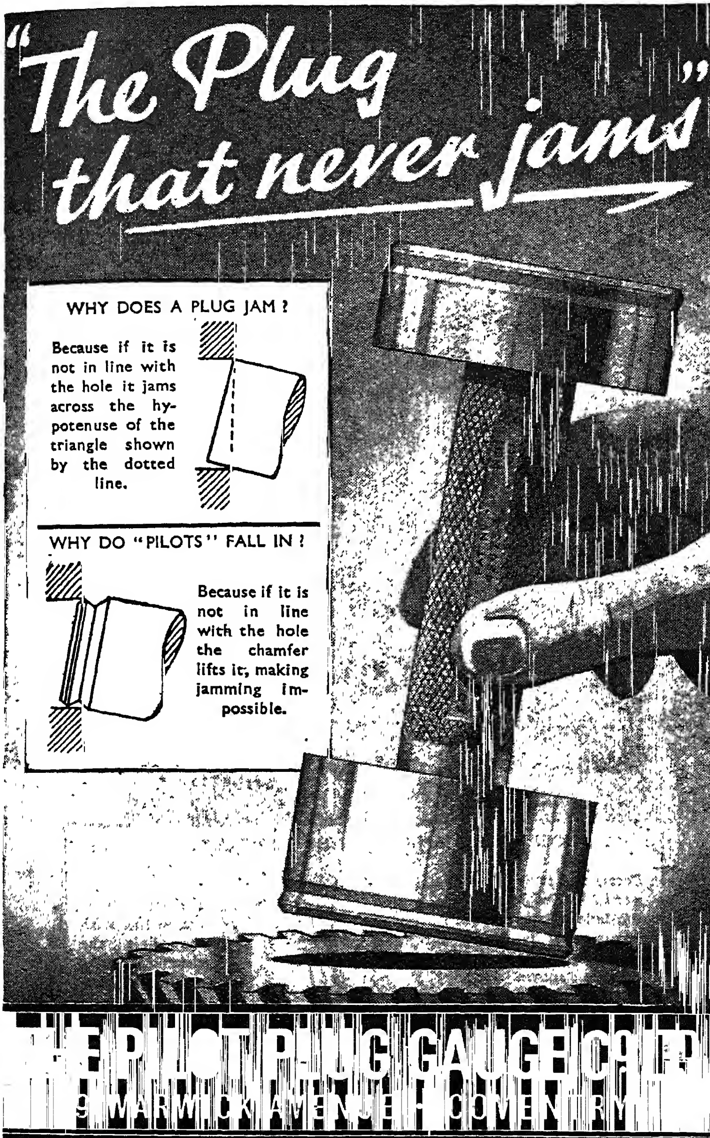
Bore-diameter Measurement.—The most common inspection device for checking internal diameters is undoubtedly the plug gauge. So much depends upon its use that a few notes on the subject will be of interest.

The three types in general use are shown in Figs. 79 and 80. The reproduction is taken from "Recommended Designs for Gauges." Copies of this (B.S.1044) specification may be obtained from the British Standards Institution.

A of Fig. 80 is a "Go" gauge of reference type, extensively used for gauge-setting purposes. The type B, progressive gauge of maximum and minimum diameters, is suitable for open-end bores, or where the depth of bore is sufficient to allow entry of the "Not Go" into an oversize hole.

The C type is a double-end gauge, and is probably found in every workshop.

Wear Allowance.—The "Go" end is made to the maximum diameter allowable on the corresponding work parts, plus an allowance for gauge wear and inaccuracies of gauge manufacture. Obviously, it is not practicable to make the gauge absolutely correct to size. The "Not Go" member is made to component maximum diameter minus wear allowance.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WHY DOES A PLUG JAM ?
Because if it is not in line with the hole it jams across the hypotenuse of the triangle shown by the dotted line.
WHY DO "PILOTS" FALL IN ?
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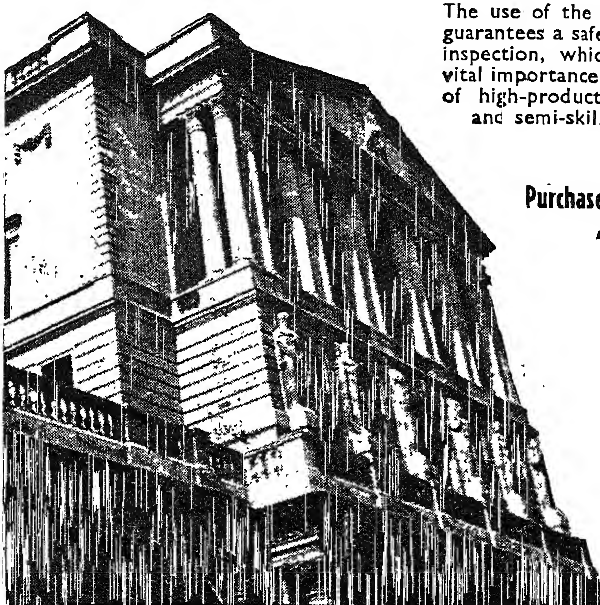

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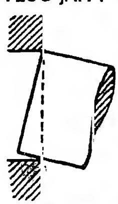

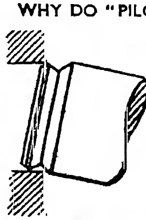

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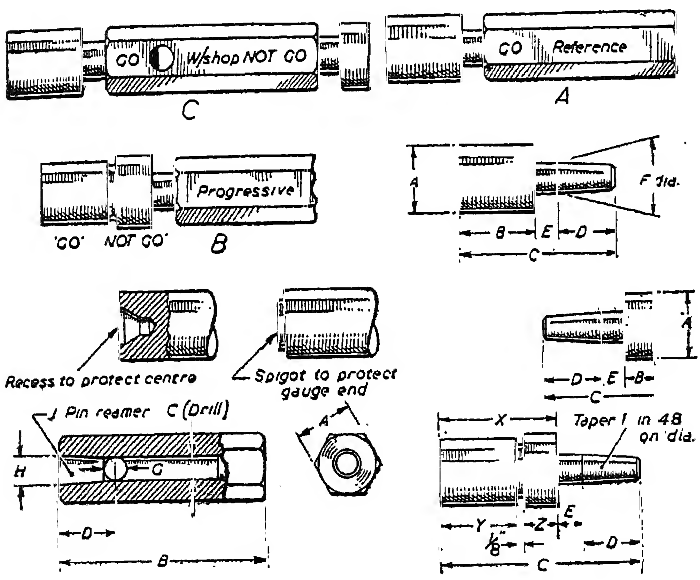
In general, the margin of wear allowance, which caters for errors of mechanical and human element in gauge making, is equivalent to 10 per cent. of the total work diameter limit for the " Go " end, and 5 per cent. for the " Not Go " gauge. An example of this is shown in Fig. 81, and from this will be seen the direction of the percentage, which is frequently confusing in practice.

A Gauging Difficulty.—If the work produced is to close limits, then the wear allowance occupies a fairly large portion of the work tolerance. Difficulties associated with boring, by any method, are aggravated by the plug gauge " jamming " in the bore.

A commendable practice is the " Pilot " system illustrated in Fig. 82. The diagram of Fig. 83 shows the pilot for " open " or " blind " bore checking. Due to



Figs. 79 and 80.—Standard plug gauge design (for dimensions see Table XIII).

the guiding action of the piloted end, a very considerable saving of time, temper and scrap work results in adopting this method.

A reinforced plug gauge similar to Fig. 84 may, with advantage, be used on aluminium and similar materials of a highly abrasive nature. The gauging surface is inset with Stellite ribs to resist wear.

Cylinder Gauges.—In keeping with the present-day tendency of using adjustable gauges whenever possible, indicating gauges are used, and have the advantage of application to a widely varying range of diameters in production, " quality control," and also in gauge inspection.

A typical cylinder gauge is shown in Fig. 85, which illustrates the simplicity of this method.

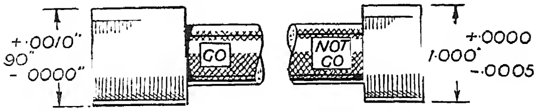


Fig. 81.—Allowance for wear and gauge-making inaccuracies.

With a dial graduated in 0·0001 in. divisions, the visual magnification is more than 600 to 1, so that 0·001 in. variation of the bore diameter is shown by about ⅝ in. movement of the indicating finger. Taper, bellmouth, and ovality are easily disclosed, and measurements may be estimated to 0·00003 in.

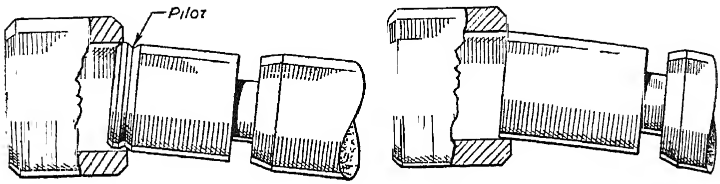


Fig. 82.—Action of Pilot plug gauge.

"Mercer" gauges are available for bores up to 36 in. in diameter, with 0·0001 in., 0·0005 in. and 0·01-mm. readings of the dial gauge.

Air-operated Gauges.—The Solex air-operated gauge is used for precision measurement, a process which, by virtue of its design, may be carried out by semi-skilled labour. Fig. 86 shows this gauging apparatus in use.

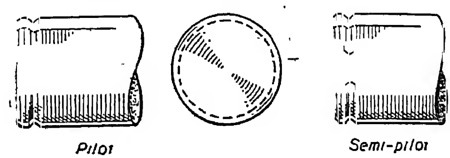


Fig. 83.—Gauge for open or blind holes.

Using a suitably graduated scale, inaccuracies are measurable to less than 0·00005 in. units. Thus, work parts may be graded into classified groups for very precise selective assembly of mating members.

The operation is speedy, one plug only being used. Size errors are indicated on a graduated scale attached to the vertical pressure column. The gauge does not rapidly wear, friction being countered by the measuring apertures being below the skirt diameter of the gauge.

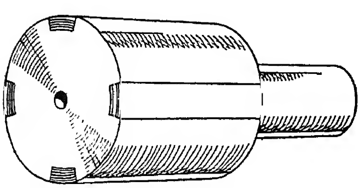
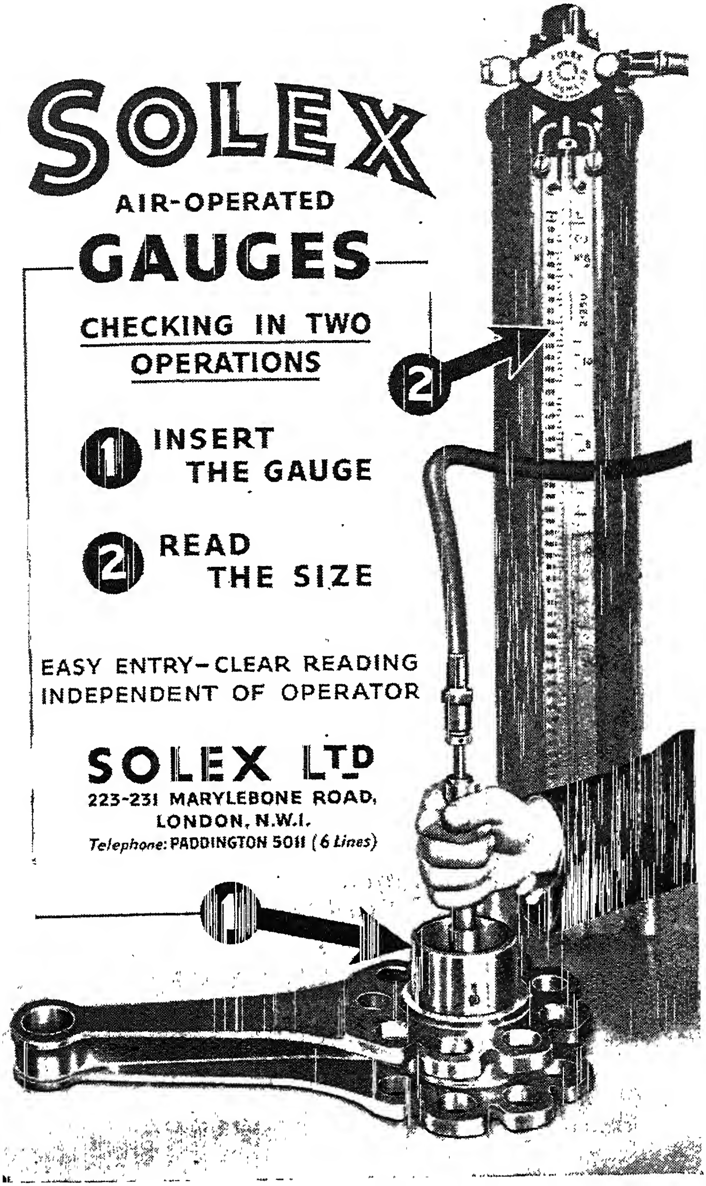


Fig. 84.—Reinforced plug gauge for hard-wearing surface.

Fig. 87 shows a close-up view of the gauging member and work-piece being checked. The air aperture will be noticed on the plug gauge; also will be seen the scale, in this instance graduated in 0·0001 in. divisions.

The amount of air escaping from the apertures determines the rise or fall of the coloured water in the vertical glass tube, and shows, in direct proportion, the diameter of work being examined. From the sectional diagrams in Fig 88 is seen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AIR-OPERATED
GAUGES
CHECKING IN TWO OPERATIONS
1 INSERT THE GAUGE
2 READ THE SIZE
EASY ENTRY—CLEAR READING
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2

the jets through which the air passes from the main supply. The two gauges shown are specially designed for paying particular attention to alignment and ovality. Solex gauges are made for checking "blind" or "open" bores, and are used on holes less than $\frac{3}{16}$ in. in diameter.

Plug-gauge Measuring.—This gauge-inspection operation is conducted with the use of slip gauges and comparator. The set-up shown in Fig. 89 illustrates the arrangement usually adopted to guard against errors introduced by thermal expansion.

By comparison with the adjusted reading of the comparator when set with slip gauges, any size discrepancies of the plug gauge are indicated on the comparator scale.

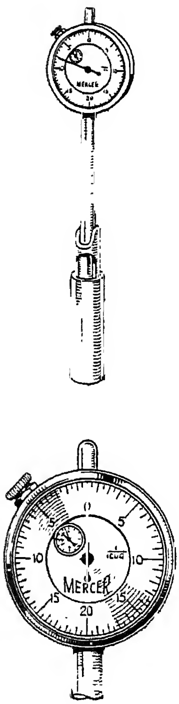


Fig. 85.—Mercer cylinder gauge in use. Checking the bore diameter for size, taper, and ovality.

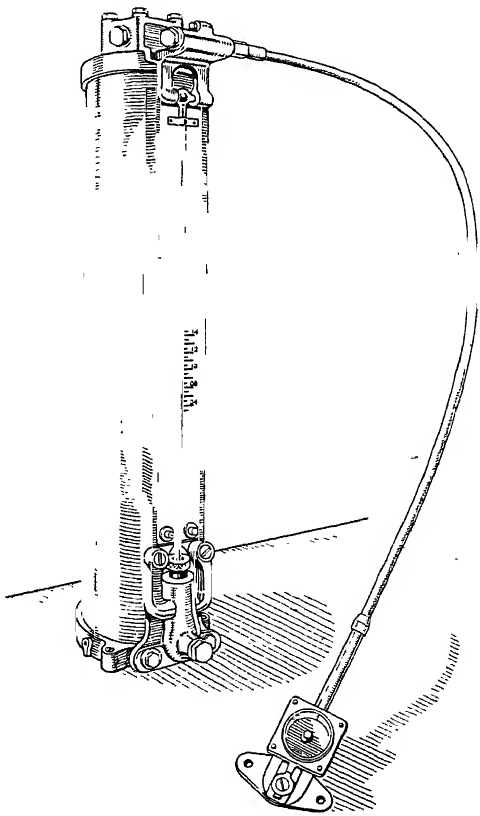


Fig. 86.—Air-operated gauging apparatus.

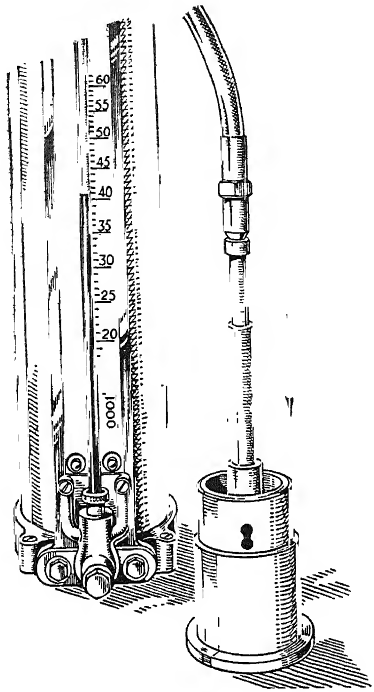


Fig. 87.—Measuring bore diameter, "Solex" method.

The plug gauge and slips are first scrupulously cleaned and placed on the comparator table. A bridge is formed by placing a steel block across the gauge and slips. The comparator anvil is brought into contact with the bridge and left in this position for a few minutes.

Any significant difference is thus compensated. The foregoing method does not readily disclose the presence of errors of "lobing" of the plug gauge because only two-point contact is made. The plug is rested in a vee-block, and rotated under the comparator anvil, making three-point contact, which would then allow comparator measurement of the "lobing," if present in the gauge.

The set of slip gauges generally used consists of eighty-one rectangular blocks of nickel steel and are divided into four series.

The first consists of nine blocks from 0·1001 in. to 0·1009 in. with increments of 0·0001 in. Forty-nine slips comprise the second series and increase in thickness by 0·001 in., and from 0·101 in. to 0·149 in. Next is the series of nineteen, the thickness increasing in steps of 0·05 in. from 0·050 in. to 0·950 in.

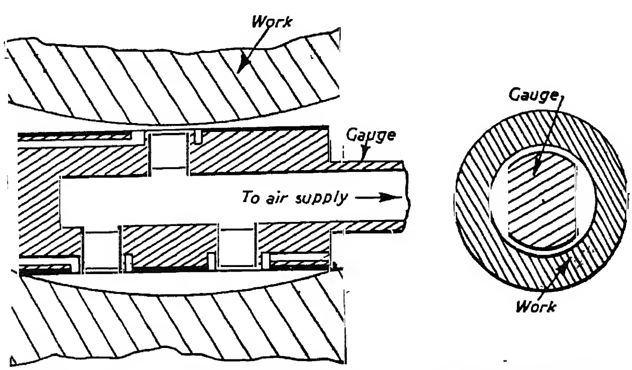


Fig. 88.—Checking ovality and alignment of bore, with air-operated gauge.

TABLE XIII

Handle Sizes (in Inches)

No.	Range		A	B	Drill Size C	D	Dia. G	H		J
	Max.	Min.						Min.	Max.	
2	0·365	0·510	$\frac{1}{2}$	3	L	$\frac{25}{32}$	$\frac{15}{64}$	0·309	0·31	$\frac{5}{16}$
3	0·510	0·825	$\frac{11}{16}$	$3\frac{1}{4}$	$\frac{25}{64}$	$\frac{27}{32}$	$\frac{11}{32}$	0·409	0·41	$\frac{5}{16}$
4	0·825	1·135	$\frac{7}{8}$	$3\frac{5}{8}$	$\frac{37}{64}$	1	$\frac{3}{8}$	0·609	0·61	$\frac{5}{16}$
5	1·135	2·510	$1\frac{1}{8}$	4	$\frac{25}{32}$	$1\frac{1}{4}$	$\frac{7}{16}$	0·809	0·81	$\frac{5}{16}$

Plug Dimensions (in Inches)

No.	Standard				Progressive				D	E	F	
	"Go"		"Not Go"									
	B	C	B	C	Y	Z	X	C			Min.	Max.
2	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{3}{8}$	$1\frac{3}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$2\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	0·309	0·31
3	$\frac{7}{8}$	$1\frac{7}{8}$	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$	0·409	0·41
4	1	$2\frac{3}{16}$	$\frac{5}{8}$	$1\frac{13}{16}$	1	$\frac{5}{8}$	$1\frac{3}{4}$	$2\frac{15}{16}$	$\frac{7}{8}$	$\frac{5}{16}$	0·609	0·61
5	$1\frac{1}{4}$	$2\frac{5}{8}$	$\frac{3}{4}$	$2\frac{1}{8}$	—	—	—	—	1	$\frac{3}{8}$	0·809	0·81

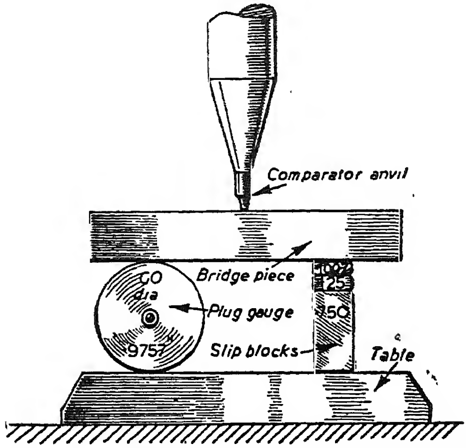


Fig. 89.—Equalising temperature of gauge and measuring equipment.

The four remaining blocks advance in 1 in. units, from 1 in. to 4 in.

Various accessories are used in conjunction with the slip gauges for measuring internal and external dimensions, and for marking out work, etc.

Other methods in general use are as follow:

The length bar (Fig. 90) is used on large diameters with a coarse tolerance; a separate " Not Go " being used.

A similar design shown in Fig. 91 has the advantage of an incorporated " Not Go."

The slips, jaw-anvils, and holder (Fig. 92) are an ideal means of gauging "short-order" production, especially on non-standard diameters.

The taper parallels illustrated in Fig. 93 are supplied in sets with a range of ½ in. to 3 in. diameters. They are very useful and convenient, having a great variety of applications. The parallels are inserted in the bore, adjusted to make good contact, and measured with a micrometer whilst in position.

Gauge Life.—The service life of a gauge depends on many factors, principally fair usage, the gauge material in view of the material composition of work to be gauged, and the surface finish of both the gauge and component.

It is generally advisable to finish the gauges with a lapping operation, the additional cost being amply repaid with a longer gauge life.

Unfortunately, there exists a practice, perhaps remote, of gauge-wear allowance being so great that the saving in gauge replacement is offset by the increased productive costs due to the serious restriction of tolerance available to the workshop.

In deciding this allowance, the abrasive qualities of the work parts should be considered and often results in less allowance being required than is laid down by standard practice.

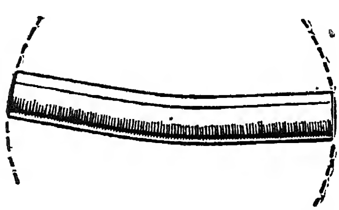


Fig. 90.—Length-bar type of plug gauge for very large diameters.

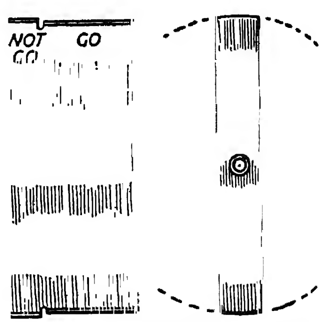


Fig. 91.—Plate-type plug gauge for large diameters.

Periodical investigation into even such obvious conditions cannot be overcommended.

An experience worthy of mention was the adopted method of copper plating

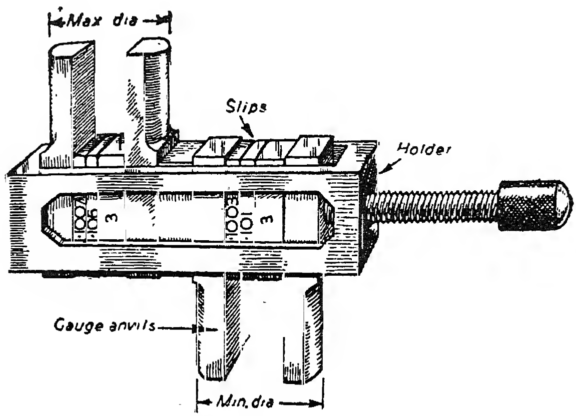


Fig. 92.—Set-up for checking bore diameter.

the plug gauge " Go " end, about 0·0005 in. in diameter. The gauge was used until such time as the copper had worn away and the hardened gauge surface was visible.

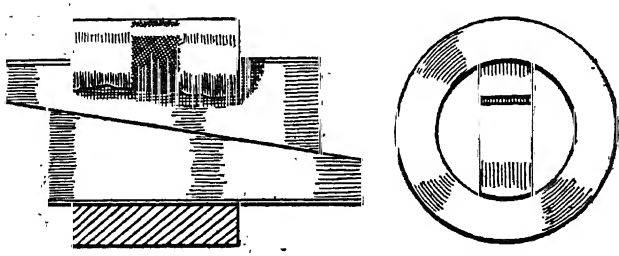


Fig. 93.—Taper parallels for internal diameters.

The " plating " process in this instance took a matter of minutes and resulted in the gauge being everlasting.

Classes of Dies.—In the majority of press tools the die is usually secured to a bolster which in turn is clamped to the bed of the press and the punch is carried in the travelling member or ram. But many advantages are gained by reversing the order of things and placing the die above in the ram and mounting the punch below in the bolster.

Compound dies are a typical example. In these tools the punch carries an inside die, and the die also has a punch. In cases such as this it is impossible to ascertain which is the die, because each portion of the tool functions both as a punch and die.

Press tools are classified as follows :

(1) Those that operate on the material by cutting are known as piercing dies, blanking dies, notching dies, and cropping dies. Perforating tools are also under this heading.

(2) Tools that perform on a component already blanked in which the piece is bent or formed are referred to as bending dies, forming dies, and curling dies.

(3) Various types of tools that compress the metal are known as extending, embossing, swaging, and coining dies.

(4) Forming the material by the action of drawing into dies is a further example, and these tools are called drawing dies, reducing dies, and bulging dies.

Though the tools are grouped together under these various classes, a great many of them may incorporate perhaps one, two, three, or even four of the types in one particular tool. These are known as multiple tools, progressive dies, tandem or follow-on tools.

Blanking and Piercing Dies.—These types of tools are those most extensively used in presswork. In fact, the many different features common to blanking tools are found in the construction of piercing punches. Piercing punches are really internal blanking tools, and whereas in the latter the outside scrap is dispensed with, the internal material in the piercing dies, or slug, as it is known, is discarded.

Blanking and piercing dies usually consist of a bolster on which is secured the die, a stripper which prevents the material from rising on the upstroke of the ram, a stop to position the strip prior to the ram descending, a guide to ensure the stock is maintained true with the die opening, and a punch. Guide pillars are a great asset on all types of tools, and should naturally be provided on blanking and piercing tools.

Pressure required for Blanking.—Blanking tools shear the metal by cutting blank through the material. If the shearing strength is known, then the pressure necessary to cut the blank is found by the following formula :

Pressure in lb. = thickness of material $\times$ length of cut $\times$ shearing strength.

Table 1 gives the approximate pressure in pounds for 1 in. length of cut when shearing steel or brass. For the actual pressure required multiply the figure in the table by the length of the cut.

These figures will vary with the condition of the tools. Again, when a shearing angle is incorporated these pressures are reduced by about one-half for material up to $\frac{1}{4}$ in. thick. Above this figure two-thirds of the tabulated figures are required.

Amount of Material between Blanks.—The material between the blanks is somewhat governed by the thickness of the material, and may vary considerably according to the size and shape of the piece. For stock up to $\frac{1}{16}$ in. gauge, $\frac{1}{16}$ in. between the pieces will give satisfactory results ; thicknesses up to $\frac{1}{8}$ in. demand a slight increase, and $\frac{1}{16}$ in. to $\frac{1}{8}$ in. is adopted as a general rule.

The shape of the blank and the accuracy may allow these figures to be modified, thereby using less stock with a correspondingly less waste. But where narrow strips of material occur in the finished blank a tendency to "draw" into the die will result if this is carried too far. This point needs particular attention when establishing the position of the blanks.

The Position in relation to Die Centre Line.—The position in relation to

die centre line and the amount of material between the blanks is closely allied and is, of course, governed by the size and shape of the piece.

No hard-and-fast rule is therefore possible. Pieces are positioned crosswise, lengthwise, and angular, each with a view to economising in stock. Passing the material through the tool to produce blanks on one side and turning it over to pass it through a second time is again common practice. By this means projections are placed behind each other in close proximity.

Button Dies.—These dies are inserted in the die plate, thereby frequently eliminating the use of a large hardened die.

Table 2 shows the dimensions for these dies, which are of cast steel hardened and ground, the outside diameter being a drive fit in the die plate.

Increase in Size of Opening when Regrinding Cutting Face.—Frequently it becomes necessary to determine the size of the die opening after a regrind, to ascertain whether the die will produce components within the drawing limits. The accompanying table 3 indicates the increase in the size of the die on one side only, corresponding to a given amount removed from the die face with varying degrees of taper.

Usually the die openings are first manufactured with a straight portion of about $\frac{1}{8}$ in. and relieved as shown in the illustration to a suitable angle; obviously it is only when this initial opening is ground away that the die increases in size.

The figures given in the table must be doubled to obtain the actual amount of increase if the die has two working faces.

Penetration.—Table 4 shows to what extent blanking and piercing tools have to penetrate to effect the complete severance of the piece.

Sectional Dies.—Punches and dies made in segments have many advantages over tools of solid construction, and the possibilities of making them in sections should not be overlooked. Sometimes the profile of the die is very complicated; often the job is large and the hardening problem is the chief thing to be considered; a certain portion of the tool is liable to frequent breakage and making the die in segments would considerably cheapen manufacture. Again, accuracy is a feature which must not be forgotten; sectional construction will allow the profile to be ground. All these points should receive careful thought and, provided each piece of the die is carefully tenoned, screwed, and dowelled into place, sectional dies have many advantages over the solid tools.

Clearance between Punches and Dies.—Thickness of the material is the governing feature when determining the clearance, which for general work in brass and soft steel is found by the following calculation, viz.:

$$\frac{\textit{Thickness of material}}{20\ (5\%)} = \text{clearance.}$$

For hard-rolled steel this clearance is slightly increased and found as follows

$$\frac{\textit{Thickness of material}}{8{\cdot}3\ (12\%)} = \text{clearance.}$$

When material of a thin nature, such as sheet tin and copper, is blanked, a ragged edge is produced on the piece unless the punch and die are a close fit.

For this reason the punch is frequently left soft, and when ragged edges do appear on the pieces due to wear on the punch, it can be removed and "peened" with a ball hammer until it is larger than the die opening. Forcing the punch through the die will once again shave it to a close fit, thereby eliminating the ragged edges. Naturally, these clearances apply to both piercing and blanking tools. When blanking, the die determines the size of the component and the clearance is subtracted from the punch. Inversely, for holes the punch is made to the required size and the die carries the clearance.

In the past a certain amount of controversy has existed over this term "clearance," but present-day practice defines it as the space between the punch and die on one side only.

Pressure required for Piercing.—This pressure is calculated by the same formula as used for blanking, viz.:

Pressure in lb. = thickness of material × length of cut × shearing strength.

Table 6 gives approximately the pressure in pounds for 1-in. diameter hole in steel and brass. For smaller or larger diameter holes multiply or divide 1 by the required diameter.

Piercing Accurate Holes.—A recommendation is made that when holes require a fair degree of accuracy an allowance of from 0·001 to 0·002 in. is added to the punch, because of the tendency of the finished hole to "close in" and cling to the punch as previously stated. The size of the hole is determined by the diameter of the punch; the clearance, of course, depending upon the gauge of the material, is added to the die.

Table 1 gives the figures for practically all thicknesses likely to be used.

Punches (table 7).—These are made of cast or silver steel suitably hardened and ground. The diameter B is a drive fit in the punch plate, and is usually made about $\frac{1}{64}$ in. larger than diameter D.

Punches secured by Set Screw (table 8).—This type of punch is used for blanking and piercing, and is somewhat cheaper to install than those in the previous table. The smaller sizes up to $\frac{1}{2}$-in. diameter are made from silver steel, and above this diameter cast steel is usually the material specified.

Pilots.—Pilots are used extensively in progressive tools, and it is usual to make the radius R equal at least to the diameter of the punch. Cast and silver steel are the usual steels for these accessories.

A hole for removing the pilot is an advantage, as shown in the illustration accompanying table 9.

Shaving Dies.—These tools are used for finishing pieces accurately with a minimum of rough edges, but unfortunately their application is not very general. This is no doubt due to the fact that the blanks require a second handling, consequently we find them relegated to finishing stock of fairly heavy gauge. Some latitude is permissible in the tools for the first operation which will tend towards cheapness, and a further gain on the second tool is obtained by a reduction in the wear.

Shaving tools are particularly useful for such components as gear wheels or when a piece requires a V with a sharp corner.

Allowances for Shaving.—These allowances will vary with the thickness and hardness of the stock, and table 10 gives them for both hard and soft materials. Sometimes, if a second shaving operation is necessary, these allowances are of course increased, and it is usually sufficient to leave half as much again as required for the first shave.

The figures given are for each face, and require doubling when the complete periphery is shaved. For convenience, table 11 is included for components requiring a double shaving operation.

Usually the piece requiring a shaving operation is dropped into a recess, and either a punch is passed through the job or when the outside is to be finished the part is pushed through a die. However, when only a portion of the outside profile, or perhaps the hole, requires shaving, it is possible to perform the operation in a progressive die. First, a hole is punched where the profile needs finishing; shaving is the next stage, and finally blanking the piece.

Cropping Dies.—Closely resembling both blanking and shaving tools, they are principally used for cutting strip material to length. Producing a radius on the end of the material while cropping it to the required length is carried out with this tool.

Trimming Dies.—Again these dies are allied to blanking and shaving tools, as they are used when it is necessary to trim the edges to bring them to a final finished state.

The flange diameter of a bush that has been previously drawn is a typical example, and in cases such as this the punch registers in the part to ensure centrality before pushing it through the die.

Drawing Dies.—Drawing dies with their great variety of shapes are fairly difficult to make with the guarantee that they will work satisfactorily from the point of view of production without a fair amount of adjustment.

Depth of draw, thickness of stock, quality and texture of the material, the number of draws, and the radius at the mouth of the die are some of the factors that must receive consideration in the design of the tools. Annealing is a further

factor that frequently influences the design, and here experience is somewhat the governing feature.

Tinplate and other materials which cannot be treated without spoiling are usually finished in possibly two draws, but other materials require perhaps several visits to the furnace to produce a satisfactory component.

Brass, copper, and steel are seldom worked for more than two draws without annealing, and it is frequently necessary to treat them after each pressing. Aluminium is usually drawn slightly deeper provided a good-grade material is used.

Depth of Draw.—The depth and shape of each draw is a matter that cannot be dealt with by any textbook; so much depends upon factors over which the tool designer has no control, and it is only from experience that the design is arrived at.

Diameters of Shell Blanks.—While it is impossible to give a formula that will enable a shell blank to be accurately calculated, the following will give a fairly close approximation. Stress is laid on the fact that no allowance is made for stretch of the material.

The dimensions for cylindrical shell blanks with sharp corners are obtained as follows:

$$D = \sqrt{D^2 + 4dh}$$

where D = diameter of blank, d = diameter of shell, h = height of shell.

Similarly, for shells with radii not exceeding one-quarter height of shell, the diameter of the blanks is calculated as follows:

$$D = \sqrt{D^2 + 4dh - r}$$

where r = radius at the corner.

Radius at the Mouth of the Die.—The radius at the mouth of the die causes quite a considerable amount of trouble, either because it is too small, with the result that shells fracture, or, conversely, if too large, will result in components becoming wrinkled. A fair average is found by multiplying the thickness of stock by eight, though again an increase or decrease is sometimes desirable, depending on the nature of the work. However, this wrinkling is often "ironed out" by the introduction of a pressure pad, which should be included in the design of all drawing tools. Careful regulation of the pressure is important to prevent the possibility of the material fracturing when passing over the radius at the mouth of the die.

Clearance between Punch and Die.—When a blank of known thickness is drawn by the punch through the die which is the size of the punch plus twice the thickness of the stock, a shell is produced whose wall does not vary to any great extent from that of the original blank.

This procedure may lead to scored dies, and it sometimes occurs that it is preferable to allow approximately two and a half times the stock thickness between the punch and die.

Drawing Jobs Inside Out.—To obtain a greater depth of draw it is sometimes permissible to draw shells inside out, and to do so the tools must have a high polish and the radius at the mouth of the die be accurately finished.

Air Vent in Punches.—A small feature often overlooked which can cause considerable trouble is lack of a proper air vent, particularly when drawing deep shells. Usually a small hole drilled along the axis of the punch which is joined by a similar crosshole sufficiently far up the punch to clear the shell is adequate.

Double-action Tools.—Double-action tools are used on presses that have two slides. The outer slide proceeds slightly in advance of the inner and carries the blanking punch, while the inner slide accommodates the drawing punch. After blanking the piece, the outer slide dwells for about a quarter of a revolution of the crankshaft, and the tools are so constructed that the blanking punch of this slide serves as a pressure plate and securely holds the work-piece, while the drawing punch completes the operation. The pressure of the outside slide can be regulated.

Triple-action Tools.—These tools operate exactly the same as those of the double-action type as regards the outer and inner slides, but a third slide is incorporated in the bottom of the press. This slide may be used for a forming operation, or perhaps embossing a name on the piece as it is pushed through the die by the inner slide. Thus, in triple-action tools it is possible to blank, draw, emboss, etc.

Lubricant.—Paraffin or kerosene are suitable for shallow draws, but for anything that is of a deep nature vaseline, lard, petroleum jelly, or oil are preferred.

BENDING AND FORMING DIES

Spring in Material.—Difficulty is sometimes experienced when bending work, due to the pieces springing back after the pressure has been released. Soft brass and aluminium will sometimes remain as bent, but hard brass and steel require to be bent farther than that specified on the component drawing to compensate for natural springiness.

Tryout of the tools in the soft state to enable any adjustments necessary to the form is the only solution.

Bending Allowance.—When bending and drawing materials, the developed length must be known to ensure that accurate blanks are cut. With the varying hardness and tensile strength of the different materials, it is difficult to accurately calculate this length with a certainty, but the bending and drawing tools will produce a component that is correct if the dimensions specified are close.

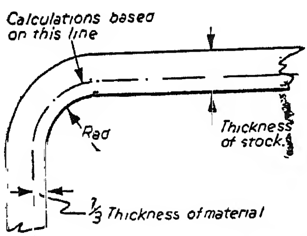


Fig. 1.—Calculating bending allowance.

When cases of this nature occur the usual practice is to manufacture the bending and drawing tools before making the blanking dies. Tryout of these tools with a blank cut out by sawing and filing to the calculated figures will reveal any discrepancy due to the material.

In scores of cases, however, the calculated method is sufficiently accurate, and the manufacture of the blanking tool can proceed ahead of the other tools and so save making blanks by the laborious method of sawing and filing.

When material is bent it stretches on the outside of the bend and compresses on the inner radius. Now, if the compression and tensile strengths of the metals were equal, then it follows that the inner and outer radii would stretch and compress an equal amount, and the calculations would be based through the centre of the stock thickness.

Materials will stretch more than they will compress, and to meet this contingency a rule has been adopted which states that the length is calculated along a line a third of the stock thickness from the inside bend. Therefore a radius in a corner of a bend is taken as the inside radius plus a third of the thickness of the material.

Fig. 1 will assist in making this point perfectly clear.

A useful rule for calculating the extra length of stock necessary to allow for bends is to add from one-eighth to one-half of the thickness of the stock for each bend to the sum of the inside dimensions of the finished piece. This will give the length of the material before bending. It will, of course, be understood that exact data for bending allowances cannot be given, as the nature of the stock is variable, and trial and error with the particular material to be bent is advisable. The bending allowance will also vary according to the material, that is to say, whether it is aluminium, iron, steel, etc.

The reader is referred also to the section on calculating bending allowances (see index).

Alignment of Punches and Dies.—Provided reasonable care is observed, jobs of a simple nature that are not produced in great quantities do not need guide pillars as an aid to accurate location of the tools. Care in setting and adequate clamping to the bed of the press are usually sufficient. However, mass production and the use of unskilled labour make it imperative that a means to locate the punch and die is included in their construction. This is usually by the provision of two guide pillars, which are driven into the bolster and are a slide fit in the top plate.

These pillars are advantageous in not only ensuring the accurate setting of the punch and die and thereby reducing the chances of breakage to practically nil, but they greatly assist in fast setting of the press.

Top plates and bolsters are of a good-grade iron; the pillars are hardened and ground, as are the bushes.

Pillar Sub Press.—This type of tool is the most extensively used.

Cylindrical Sub Press.—This tool has a ram sliding in a bearing of white metal which is held in a housing by a screw cap at the top. Tapered externally to allow it to be adjusted to eliminate wear, this sleeve aligns the punch with the die, the latter part being registered in the base which is also machined to locate the housing.

Various Types of Presses.—When designing a set of press tools, some thought as regards the type of press on which the tool will operate is necessary and important. Small work, which is best performed on a light press, should not be placed on a large slow hydraulic machine; similarly, working a big blanking tool on a small screw press is equally ridiculous and may soon result in straining it.

Care then in the choice of the machine must receive consideration, and every job be examined to ensure that the above-mentioned mistakes are avoided.

Screw Press.—This type of machine is so common—it appears in practically every workshop, often finding a variety of uses in a machine shop—that it needs no description. Sometimes this machine is referred to as a fly press, and it is used extensively on work of a light nature.

Pressure from a Screw Press.—The pressure exerted by a screw press is dependent on the length of the lever attached to the screw, the pitch of the screw, and the force applied on the lever.

Thus,

$$\text{circumference of swing} \times \text{number of threads per inch} \times \text{force} = \text{force or pressure exerted by the press.}$$

Example.—A force of 100 lb. acting on a lever 20 in. long which is attached to a screw having a pitch of $\frac{1}{2}$ in. exerts a pressure as follows:

$$3\tfrac{1}{7} \times 20 \times 2 \times 100 = 12{,}560 \text{ lb., or approx. } 5\tfrac{1}{2} \text{ tons.}$$

Screw Press (Power Driven).—A power-driven screw press is very similar to the machine previously described, with the exception of a large flywheel in place of the lever at the top of the screw. This flywheel is driven by two friction discs, which are in turn belt driven. An apparatus for disengaging the drive is also installed. The discs revolve the flywheel and the energy stored in the wheel is applied to the ram, thereby providing a blow of constant pressure.

Foot Press.—Another press for work of a light nature which is pedal operated.

Double-action Presses.—Double-action presses are fitted with two slides permitting multiple operations to be performed.

The material is placed in position and the outside slide descends and blanks the piece, at the same time carrying it on until it is suitably "nested." This slide is then arrested and holds the blank under a pressure which can be regulated for about one-quarter of a revolution of the crankshaft. The inner ram continues its downward movement and draws the blank to shape.

Inclined Presses.—By the aid of a screw mechanism the ram is inclined towards the rear of the machine to an angle of 45 degrees; thus it is possible for the work to fall away by the action of gravity.

Open-back Presses.—This term is used to distinguish those machines that

have their columns positioned at the rear of the crankshaft. Also an opening at the back enables the strip to be fed from front to back or from side to side.

Pillar Press.—This machine has the columns so placed that there is no overhang, and the feeding of the material is limited to passing it from front to back.

Turntable Press.—The table of this press is provided with an indexing mechanism which is controlled by the movement of the ram and securely locked in the correct position as it descends. The operators merely place the pieces in the die at the station immediately in the front of the machine, a fresh station presenting itself at each stroke of the ram. The finished components fall either to the rear or underneath the machine.

Hydraulic Presses.—Hydraulic presses are not so extensively used as the mechanically operated type. This, no doubt, is partly due to the cost of installation which, when the price of pumps and valve gear is included, is inclined to be high. Nevertheless, for certain classes of work of a heavy and cumbersome nature, and where speed of operation is not an essential feature, they are perhaps superior to an ordinary mechanical press.

Tablet-making Presses.—The presses which are used in the manufacture of tablets for compressing them from powder to solid tablet form have a hopper in which quantities of the powder are placed prior to a certain measured quantity being dropped into the die.

The tablets are automatically ejected and drop away into a receptacle.

Automatic Feeds.—Automatic feeding mechanisms have a great advantage over hand feeding on some classes of work and must be seen to be really appreciated, often at a production rate of several hundred per hour. The rollers are adjusted to move the stock forward at a uniform rate, and may be hinged to the side of the bed when setting the tools.

Press Dwell.—The term "dwell" as applied to a power press is the period of stroke during which the maximum pressure is exerted, i.e. in the ordinary crankshaft type the "dwell" is that period at the bottom of the stroke or thereabouts.

Obviously, the ram is only instantaneously stationary, but the rate of increase or decrease of pressure exerted is at its lowest value. Hence, the effective "dwell" in this mechanism is not really very long in duration.

In certain types of operations, e.g. coining, embossing, etc., the "dwell" must be considerable, so that other forms of mechanism must be introduced, the usual type being the knuckle-jointed mechanism.

However, in some cases it is desirable to operate the ram by means of cam action, when the return can be as quick as possible and the "dwell" as great as possible, but the limitations here are due to the lesser rigidity.

Toggle Press.—The toggle press is the last word in long "dwell," and is used extensively in the production of very deep-drawn parts such as buckets and general enamel ware. These presses are of an open type, with two pairs of toggles actuated by eccentrics, and often with a subsidiary single-throw crankshaft-operated ram inside the main one. The object of this is to perform double drawing in one operation.

The first cut and form is done in the first instance by the toggle ram and the "dwell" thereof utilised to act as a blank-holder pressure, and the secondary crankshaft ram follows on to do the redrawing whilst the metal is still hot. Here it is obvious that the usually necessary annealing process between successive redraws is cut out, so that in actuality two definite operations are dispensed with.

Press Selection

Correct Press Type.—Here experience only counts.

Whilst a job might be done on any one of several types, in most cases there is a best type on which production will be highest.

Generalisations are always dangerous, but below is given a broad summary of common press types and suitable jobs for them.

Single-acting Open-fronted Presses.—These are usually made inclinable, so that pressings, etc., may fall away by gravity. They are used as general-

purpose presses for the smaller work. Suitable for light blanking, not usually over 50 tons. For all manner of raising, forming, bending, etc., dies.

Single-acting Double-sided Presses.—Used for all heavy blanking, raising, etc., above the open-fronted range.

Made in all sizes up to 80 in. or more between standards and tonnages up to 500 tons and occasionally beyond this.

Smaller sizes usually have solid frames, and the larger sizes are built up, i.e. sides, bed, and bridge of separate castings held together by tie rods through all the parts.

When fitted with air cushion they have superseded the larger toggle double-acting presses, at least on comparatively shallow draws.

Double-acting Presses.—For all drawing work. Smaller sizes have blank holder cam operated. Heavier types of blank holder are operated by toggle levers; combination cut draw work may be done in lighter types.

Horn Presses or Side-wheel Presses.—Used originally for horning or grooving side seams, but when fitted with table (usually adjustable) suitable for light punching and raising and similar operations.

Table can be made to swing out so that press can be used for both purposes. Very useful for light work on large sheet-metal articles requiring clearance on press front.

A further point in selecting the correct press type is that of deciding on the choice between a geared or ungeared press. Generalising again, direct-driven presses are used generally for work in which the pressure is required over a very small fraction of the working stroke, as in blanking, piercing, etc. If the work to be done is spread over an appreciable portion of the working stroke, then geared presses are to be preferred.

Most presses above 50 tons are better geared, and the gear ratio chosen to suit the conditions.

Correct Press Size.—Mathematics can aid experience here, but a very careful scrutiny is always required.

The sizes of press bed, ram face, etc., required are easy to establish. Then the "daylight" (distance bed to ram) and stroke have to be determined.

Bear very strongly in mind that the pressure given by the press declines considerably away from the bottom of the stroke. The bottom of stroke tonnage usually given is far from an ideal press yardstick.

For blanking work only it is useful, but for drawing work the pressure required at the beginning of the draw and the depth of draw should be considered.

The press capacities are better expressed in inch-tons.

The bottom of the stroke pressure exerted by a press can be determined approximately from the formulæ:

Press capacity $= Cd^2$, where d is the crankshaft diameter and C is a constant.

The value of the constant varies with a number of factors, such as type of drive, stroke, press type, etc.

The following approximate rules might be given:

For double-crank, double-sided presses, stroke not exceeding crank diameter $C = 4$.

Ditto for very short strokes $C = 4{\cdot}5$ to 5.

For single-crank open-fronted presses, short strokes $C = 3{\cdot}5$.

(Bear in mind that often in these presses the press frame is the weaker member, and care should be taken to see that it is adequate.)

For end wheel or horn presses $C = 2{\cdot}5$.

Drawing press sizes are easy to determine, as the maker usually specifies maximum depth and diameter which may be drawn. Finally, the press maker should always be advised of the details of the maximum work the press has to perform. It is easier and better for both if this is done, instead of giving plain tonnage specifications.

Finding Blank Sizes for Seamless Shells

Blanks for Cylindrical Shells.—Blanks for cylindrical shells may be calculated to a degree very near to the actual blank. Many formulæ have been deduced, all on one of the following three basic assumptions:

(1) That area of blank and shell are equal.
(2) That volume of shell and blank are equal.
(3) That weights of shell and blank are equal.

The second class of formulæ, the volumetric, will be disregarded here, being principally of use where the stock thickness changes considerably in the draw. The area formulæ are the easiest to establish, and give results quite near enough for most purposes, even though the basic assumption is not correct in practice.

For aid in calculations of formulæ, on p. 805 are given formulæ for areas of most common cylindrical shells, and formulæ are established as follows :

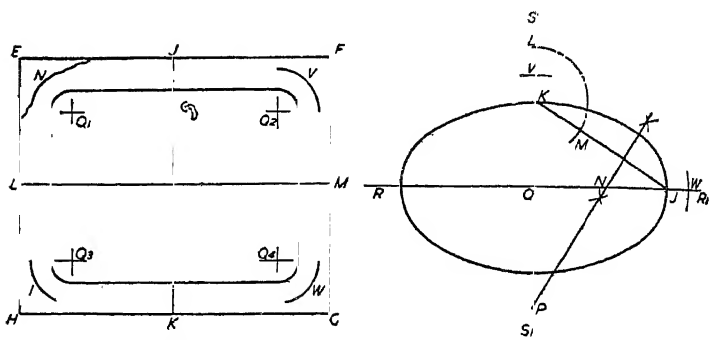
Eq. 1.—Cylindrical shell with sharp corner top diam. $dht = h$.
Total area = Area top + area sides.

$$\text{(from tables)} = \frac{\pi d^2}{4} + \pi dh$$

$$\text{Area blank} = \frac{\pi D^2}{4} \text{ (where D = blank diameter)}$$

$$\text{then,}\quad \frac{\pi}{4}D^2 = \frac{\pi}{4}d^2 + rdh,$$

$$\text{from which, } D = \sqrt{(d^2 + 4dh)}.$$



Figs. 2 and 3.—Finding blank sizes for rectangular and oval shells.

Eq. 2.—Cylindrical shell, with corner radius R diam. $dht = h$.
Total area = area top + area annular ring radius R + area of sides.

$$= \frac{\pi d^2}{4} + 2\pi R\{R + 7854\,(d - 2R)\} + \pi d\,(h - R)$$

$$D = \sqrt{d^2 + SR\{R + 7854\,(d - 2R)\} + 4d\,(h - R)}$$

It is not necessary, of course, to write out the formula each time.

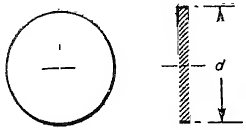
For a flanged cylindrical shell it is only necessary to add the flanged area.

On assumption that weight of shell and blank are equal, blank diameter = $1{\cdot}13\sqrt{\frac{W}{wt}}$,

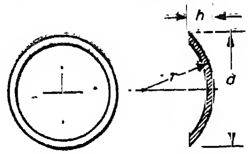
Where W = weight of shell; w = weight of stock per inch; t = stock thickness.

This formula is of particular value for shells of irregular cross-section.

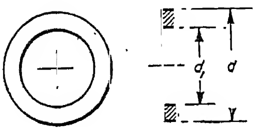
To Find the Blank for a Rectangular Shell.—Lay out on centre lines JK and LM the bottom of the shell, carefully making centres of corner radii Q_1, Q_2, etc. (see Fig. 2).



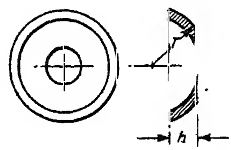
$$\frac{\pi d^2}{4}$$



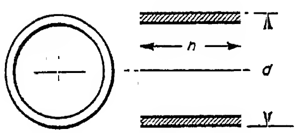
$$2\pi rh, \text{ or } \pi\left(\frac{d^2}{4} + h^2\right)$$



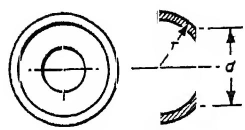
$$\frac{\pi}{4}(d^2 - d_1^2)$$



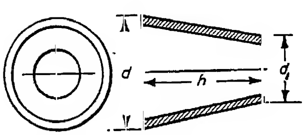
$$2\pi rh$$



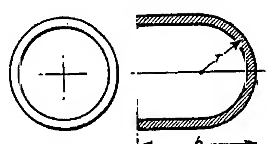
$$\pi dh$$



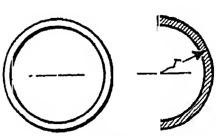
$$2\pi r(r + 0{\cdot}7854d)$$



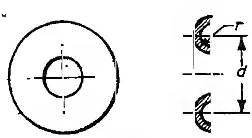
$$\pi s\left(\frac{d + d_1}{2}\right) \qquad s = \sqrt{h^2 + \left(\frac{d - d_1}{2}\right)^2}$$



$$2\pi rh$$



$$2\pi r^2$$



$$\pi^2 rd$$

Figs. 4 to 13.—Formulæ for surface areas.

On same centre lines lay out rectangle EFGH,
Where EF is $(L + 2h - 0{\cdot}86R)$ and FG is $(W + 2h - 0{\cdot}86R)$.
L = length of shell; h = depth; W = breadth; R = corner radius on top of shell between wall and top.

Assuming that at the corners there are being drawn portions of four cylindrical shells where diameter (d) is twice corner radius at bottom of shell and where depth is h with top corner radius R. Calculate the blank diameter of these four shells either by using approximate formula $D = \sqrt{(d^2 + 4dh)} - R$, or if R is large use rules for cylindrical shells previously given.

Then with radius D/2, centres Q_1, Q_2, etc., strike arcs as V.

These arcs are now to be connected to sides of rectangle EFGH by smooth curves, and this is largely a matter of experience.

Do not allow the joining curves to fall below the arcs.

This blank can now be inserted in the die and corrected by trial and error.

For taper-sided shells, flanged shells, substitute appropriate formula for

$$D = \sqrt{(d^2 + 4dh)} - R.$$

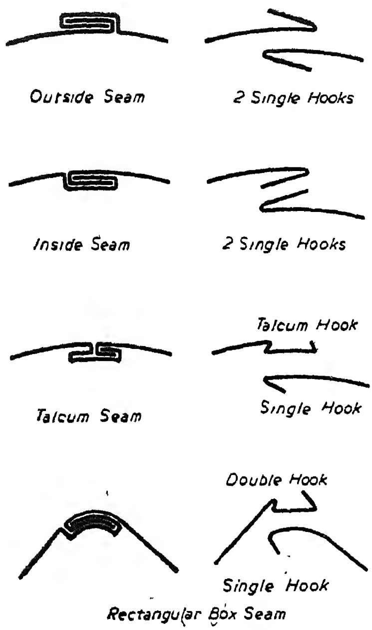


Fig. 14.—Seam formation.

To Find Blank for Oval Shell.—On centre lines mark off major and minor axes and lay out bottom of shell. This plan of the shell may be assumed to consist of four arcs joined together, with centres on major and minor axes. First find the radii of these arcs. Join KJ and mark off QL = QJ = half major axis.

Centre K, radius KL, cut line joining KJ in M. Bisect KJ at right angles and produce bisector to cut QJ in N and KQ produced in P. Then N and P are assumed centres of arcs, with radii NJ and PK respectively.

If shell has corner radius at top of R, calculate blank diameters from cylindrical shell formula as follows:

$$D = \sqrt{d^2 + 4dh)} - R$$

$$= \sqrt{(2NJ)^2 + (4 \times NJ \times h)} - R,$$

and similarly $$D = \sqrt{(2PK)^2 + (4 \times PK \times h)} - R.$$

Then with radius $\frac{D}{2}$ centre N mark of NW.

Then with radius $\frac{D1}{2}$ centre P mark of PV.

The QV is half minor, and QW half major axis of blank, and blank oval can be drawn, using inverse construction to that to determine radii above.

If the shell is taper-sided or flanged use appropriate cylindrical formulæ (see p. 804).

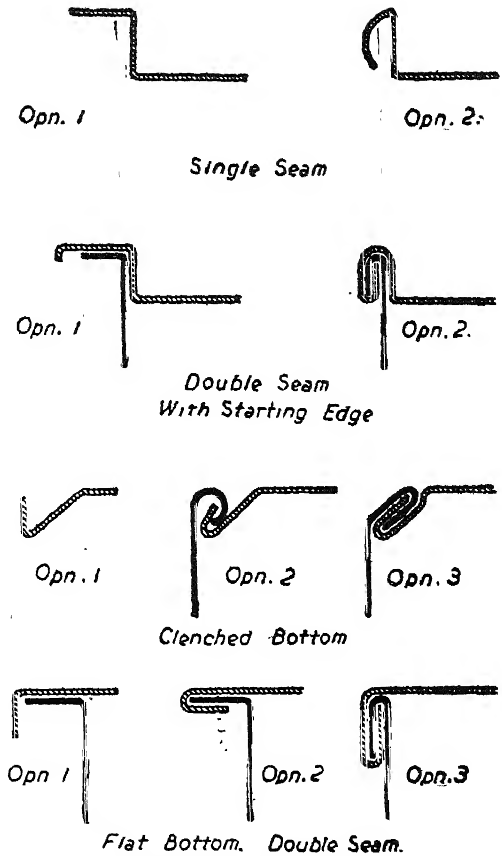


Fig. 15.—Further forms of seams.

Drafts or Tapers for Production Purposes

In various production methods in which the plasticity of material is used, such as casting, forging, moulding, etc., the walls of work-pieces, inside and outside, should be slightly tapered in the direction of removal, in order to permit an easy withdrawal of the finished components from mould or die, without a great danger of sticking and thereby the possibility for damaging either work-piece or mould or die. There is not yet established a general standard of accepted values for this purpose, and the values in the table on p. 808 have been compiled from generally accepted practice.

Blanking Pressure.—Blanking pressure = *length of cut* × *thickness of stock* × *shear strength of stock.* This is generally the maximum pressure, unless the dies are in an extremely bad condition.

The working pressure is thus generally some fraction of this, the value of the fraction depending upon shear in dies, angular clearance, clearance between top and bottom dies, sharpness of dies, etc.

The average value of this fraction will be in the neighbourhood of half, i.e.

$$\text{Working blanking pressure} = \frac{\text{total pressure as above}}{2}.$$

Shear should be such that not more than a half of the total length to be cut is actually being cut at any point of the blanking operation.

Depth shear about 10/1000 greater than stock thickness.

Shear strengths to use in above :

Soft mild steel and tinplate 20 tons/sq. in.

Soft non-ferrous metals 11 tons/sq. in.

Hard-grade non-ferrous metals 12 to 15 tons/sq. in.

TABLE OF DRAFTS OR TAPERS

Process	Material	Place	Angle: *Taper*	Angle: *Deg.*
Drop forging	Steel (general)	Forgings of uniform section	1 in 20	3
		Deep, narrow, and with narrow ribs minimum	1 in 8	7
		Internal faces, general cases	1 in 6	10
	Aluminium alloy	External faces up to $2\frac{3}{8}$ in. deep	1 in 20	3
		Above $2\frac{3}{8}$ in.	1 in 10	6
		Internal faces up to $2\frac{3}{8}$ in. deep	1 in 10	6
		Above $2\frac{3}{8}$ in.	1 in 6	10
		Bottom faces	1 in 50	1
Casting	Grey Iron	*American Practice*		
		General	1 in 100	$\frac{1}{2}$
		Small patterns	1 in 200	$\frac{1}{4}$
		Ditto minimum	1 in 400	$\frac{1}{8}$
		Continental Practice		
		Small patterns	1 in 30	2
		Limit	1 in 50	= 1
		Bigger patterns	1 in 20	3
		Extreme cases	1 in 50	1
Die castings	Aluminium	External faces	1 in 100	$\frac{1}{2}$
		Internal faces	1 in 200	$\frac{1}{4}$
Plastic mouldings	Thermo-setting materials	Up to $\frac{3}{4}$ in. height	1 in 60	= 1
		Above $\frac{3}{4}$ in.	1 in 40 to 1 in 150	= $1\frac{1}{2}$ $\frac{3}{8}$
		Average	1 in 125	26

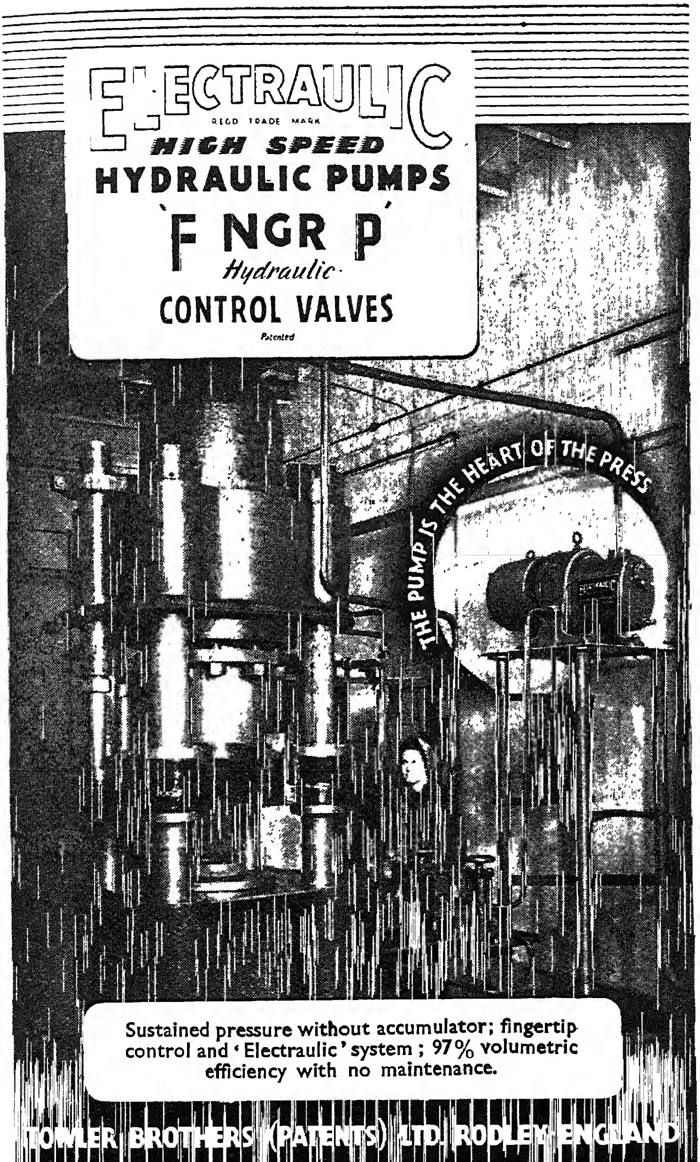
Penetration Tables.—Table showing approximate percentage dies have to penetrate into ordinary mild steel to make complete severance of material.

Thickness, in.	1	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{3}{32}$
Percentage of thickness	25	31	34	37	44	47	50	56	62	67

Drawing Work

The maximum drawing pressure is usually taken as the pressure to cut out the bottom of the shell being drawn, i.e. max. drawing pressure = perimeter of bottom of shell × thickness of stock × shear stress.

The actual pressure may not exceed 25 per cent. of this in shallow draws, but the formula is very useful in press selection.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SHEET METAL WORKING MACHINERY
PRESS TOOLS

Drawing Dies.—For cylindrical work to determine number of operations first find blank diameter. Then diameter of first operation die is given by dividing blank diameter by a factor C. The factor C varies with thickness and general physical properties stock, type of drawing dies, etc.

For good-quality deep-stamping tinplate up to, say, 1C try C = 1·7 if die has constant face pressure.

For good-quality deep-stamping tinplate up to 1C try C = 1·75 if die has constant face pressure.

For light mild steel, good quality, try C = 1·6 if die has constant face pressure.

For heavy mild steel, good quality, try C = 1·75 if die has constant face pressure.

If dies are on spring or rubber buffers, C should not be less than 1·8.

For redrawing operations after the first, the percentage reduction varies from 12 per cent. to 25 per cent. usually, the thicker the stock the lower the reduction. For soft non-ferrous metals, under ideal conditions, even 30–35 per cent. reductions may be obtained.

The redrawing of non-circular shells is always difficult, and it is not possible to deal with all the factors in this pocket-book.

Spacing Table.—When laying out a number of pin holes and the like on a pitch circle, the following table will be of great use and will save considerable time in marking off.

To find the chordal pitch, multiply the pitch circle diameter by the approximate chordal factor from the following table.

No. of Spaced Divisions	*Chordal Factor*	*No. of Spaced Divisions*	*Chordal Factor*
3	0·8660	22	0·1423
4	0·7071	23	0·1362
5	0·5878	24	0·1305
6	0·5000	25	0·1253
7	0·4339	26	0·1205
8	0·3827	27	0·1161
9	0·3420	28	0·1120
10	0·3090	29	0·1081
11	0·2817	30	0·1045
12	0·2588	36	0·0872
13	0·2393	37	0·0848
14	0·2225	38	0·0826
15	0·2079	39	0·0805
16	0·1951	40	0·0785
17	0·1838	41	0·0765
18	0·1736	42	0·0747
19	0·1646	43	0·0730
20	0·1564	44	0·0713
21	0·1490	45	0·0698

Bending Operation

Bending Pressures.—Bending pressures are almost impossible to precalculate, and where they are required to be known exactly, experiments should be made on a short length, say, of material to be bent, reproducing working conditions exactly, especially on the bending tools.

Allowance for Bends.—For right-angle bends add one-third stock thickness to inside dimensions of bent piece for each bend, i.e. for a U bend.

Approx. length of material required = 2 × depth of U + width of U + 2 $\left(\frac{T}{3}\right)$.

All dimensions measured inside U and T = stock thickness.

For right-angle bends bend at right angles to direction of grain.

Bear in mind that any "ironing" of the stock during bending increases bending pressure considerably.

Notes on Press Tools

All cutting dies where possible should be mounted on guide pillars. The initial tool cost is slightly higher but more than justifies the expense early in the tool-life.

In some raise or forming tools, the additional cost of adding guide pillars is often saved by reduction of time in tool setting.

Press tools should always be kept clean and greased.

The provision of a tool crib where tools are cleaned and examined after every use is a real money-saver.

Cutting dies should be kept sharp. By using dull cutting tools the resulting abrasion reduces the tool-life considerably. Grind lightly and often.

Hints on Ordering Press Tools.

(*a*) Specify limits required on finished pressing; the closer the limit the higher the tool cost.

(*b*) Avoid sharp bends and draws wherever possible.

(*c*) Indication of quantities likely to be produced from the tools is useful. Cheap tools can usually be made for small quantities.

(*d*) Fix the gauge of the stock to be worked in the dies.

(*e*) For tools to be mounted on pillar sets.

Give stroke and daylight (i.e. bed to ram) of presses in which the dies have to work.

Angular Shear.—This is the shear inside a blanking or punching ring. There is no fixed rule for the angle, this depending on a number of factors, as thickness, quality of stock, number of blanks required, etc.

For dies for thin stock, as tinplate, $1\frac{1}{2}$ to 2 degrees is common.

If the tolerances on the dimensions on the blank are very fine, then the angular shear is often less than 1 degree.

Clearance between Punch and Dies.—For clean cutting, there is a definite clearance between punch and die for any particular job. This is best established by experiment with particular stock, soft stock requiring greater clearances than harder stock. An average clearance for stock above $\frac{1}{32}$ in. is about 8 per cent. of stock thickness. Below this it is usual to make punch fit the die.

Lubricants.—All press stock should be lubricated before passing through press tools.

Cheap vaseline or lard oils are often used for mild steel. Soap solutions are often used for tinplate work.

Most of the large oil companies will supply specially blended oils and solutions for all press work.

Pressing Aluminium and Aluminium Alloys

With the great increase in the use of aluminium and its alloys, particularly by the aircraft industry, a brief survey of the methods used in converting sheet to pressing will be a help to those who have not been long in this branch of presswork.

Aluminium (Blanking): Pressure necessary is approximately 50 per cent. of that required for mild steel of the same gauge. Clearance between punch and die diameter should be in the region of 8 per cent. to 10 per cent. of stock thickness. Care should be taken to obtain a clean blank, particularly if the blanking is to be followed by a drawing operation, otherwise cracks may appear.

Drawing: Aluminium flows easily, but also scores easily; high polishing of punch and die is therefore necessary. A radius of 5 to 7 times the stock thickness on both punch and die is a fairly safe figure to work on. The ideal is best found by experience. An allowance of 5 per cent. for thickening of wall is recommended for clearance between punch and die.

As a lubricant, use hand oil for deep drawing and paraffin for shallow drawing.

Aluminium Alloys: These are many and varied, and duralumin, the oldest and still the most widely used, is selected as typical.

Blanking : Pressure necessary is approximately the same as mild steel.

Drawing and Bending : Needs more face pressure than aluminium. Punch and die should be highly polished to avoid marking.

Table for Bend Radii : 24 gauge to 18 gauge punch corner radius = 2 × thickness of stock; above 18 gauge, up to 14 gauge, 2½ times.

Normalising.—Heat to 495° F. generally in salt bath—can be a mixture of potassium and sodium nitrates—say 54 per cent. former, 46 per cent. latter, by weight. See that work is dry and free from grease when placed in bath.

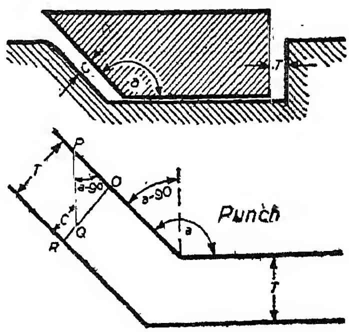
Heating medium should be arranged to give even heating to pot.

Water usually used as quenching medium. For light sheets, find by experiment best angle of part to enter bath to avoid distortion.

Punch Clearance Formula.—The following is a useful formula for calculating the clearance between the oblique planes of a punch and bend block when the horizontal planes are in close contact. The vertical planes will have clearance equal to the thickness of metal being bent; and the horizontal planes will, of course, have zero clearance when in close contact, but the oblique planes will have clearance that varies according to the angle. It is often necessary to know this clearance when machining, especially if the bend block is marked out from the punch, or vice versa.

$$C = T - T\{\sin(a^\circ - 90^\circ)\}$$

Where C is the clearance ;
T is thickness of metal being bent ;
a is included angle of bend (Figs. 16 and 17).



Figs. 16 and 17.—Calculating clearance between punch and bend block.

From this formula a graph can be plotted giving the clearance for angles 90°–180°, as a decimal fraction of the thickness of material being bent (Fig. 18).

In Figs. 16 and 17 the punch and bend block are separated by distance equal to thickness of metal being bent.

Let T = Thickness of metal.
C = Clearance when horizontal planes are together.
a = Included angle.
P = Any point on oblique plane of punch.

Drop a perpendicular from P to Q equal to T.

Through Q draw RQO perpendicular to oblique planes. Then RQ is the clearance when horizontal planes are in close contact, i.e. R.Q. = C + QO = T − C.

In rt∠ °△POQ :

$$\angle QPO = \angle a - 90$$

$$\frac{QO}{PQ} = \sin(a - 90)$$

i.e.

$$\frac{T - C}{T} = \sin(a - 90)$$

$$-C = \sin(a - 90)\,T - T$$

$$\therefore C = T - T\{\sin(a - 90)\}$$

Loading of Presses.—The kinetic energy of a flywheel is equal to pressure × stroke :

$$KE = PS$$

$$P = \frac{KE}{S}$$

If the frictional losses be neglected, it is true to say of a crank press or similar machine that

Length of stroke × Mean pressure during stroke
= Kinetic energy at beginning of stroke
— Kinetic energy at end of stroke.

The *maximum* pressure during the stroke may be many times as great as the mean pressure, and its actual value is dependent on the dimensions of the crank and connecting rod, and upon the elasticities of the different loaded members.

The question as to whether the machine is geared or ungeared does not affect the general principle except in so far as it may have some influence on the frictional losses.

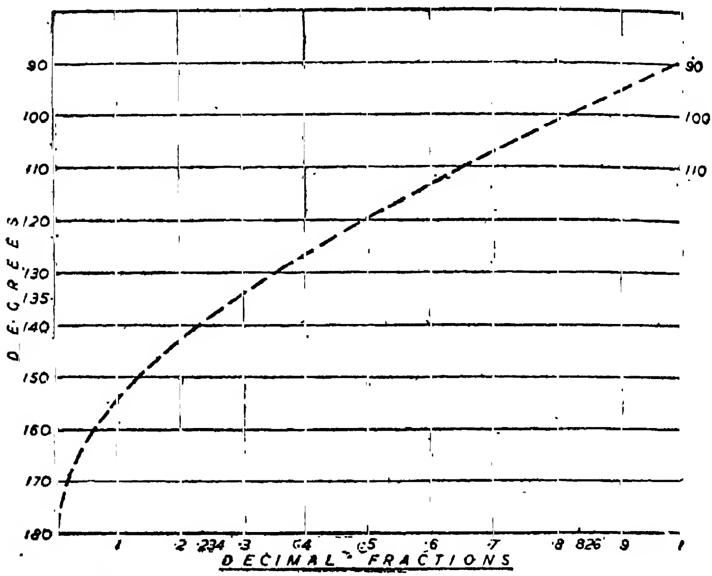


Fig. 18.—Graph showing relation between punch and die clearance.

Pressure Exerted by Hydraulic Press.—If the diameter of the ram in inches is known, as well as the water-gauge pressure in lb. per square inch, the total pressure exerted may be found by multiplying the cross-sectional area of the ram by the pressure per square inch and dividing by two thousand. The result will be the capacity in tons of the press.

Another method is to multiply the diameter of the ram by the pressure per square inch and by 0·00039, which will give the total pressure in tons.

The pressure exerted per square inch on the material can be found from the total pressure of the press and the area of the material under pressure. Multiply the total pressure in tons by two thousand and divide this product by the area of the material to be pressed. The answer will be the pressure in lb. per square inch.

To calculate the gauge pressure required when a predetermined pressure per square inch on the material is required, multiply the area of the surface under pressure by the pressure per square inch required on the material; then divide

this by 0·7854, multiplied by the square of the diameter of the ram. The answer will be the required gauge pressure. Reduced to formulæ :

A = Area of material to be pressed.
C = Total pressure of press in tons.
D = Diameter of ram in inches.
P = Water-gauge pressure in lb. per square inch.
P_1 = Pressure in lb. per square inch on material under pressure

$$P_1 = \frac{2000C}{A}. \qquad C = 0{\cdot}00039D^2P. \qquad P = \frac{AP_1}{0{\cdot}7854D^2}.$$

TABLE 1.—PILOTS

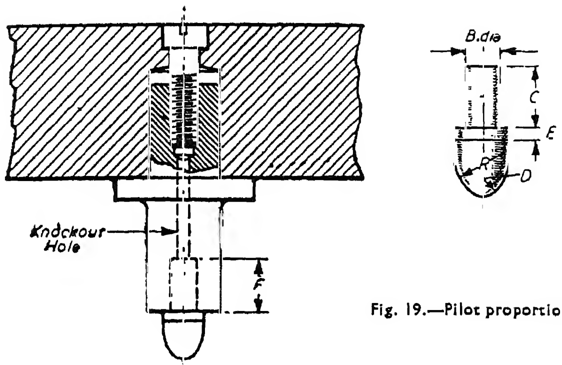


Fig. 19.—Pilot proportions.

Radius R	*Dia. B*	*C*	*Radius D*	*E*	*F*
in.	*in.*	*in.*	*in.*	*in.*	*in.*
$\frac{1}{4}$	$\frac{3}{16}$	$\frac{7}{16}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{9}{16}$
$\frac{3}{8}$	[illegible]	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{16}$	[illegible]
[illegible]	[illegible]	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{16}$	[illegible]
[illegible]	$\frac{5}{16}$	$\frac{9}{16}$	$\frac{5}{32}$	$\frac{1}{16}$	$\frac{11}{16}$
[illegible]	$\frac{3}{8}$	[illegible]	Flat end	$\frac{1}{16}$	$\frac{3}{4}$
[illegible]	$\frac{3}{8}$	[illegible]	Flat end	$\frac{1}{16}$	$\frac{3}{4}$
1	$\frac{7}{16}$	$\frac{11}{16}$	Flat end	$\frac{1}{16}$	$\frac{13}{16}$

TABLE 2.—BUTTON DIES

Dia. D	*A*	*B*	*C*
in.	*in.*	*in.*	*in.*
$\frac{3}{32}$ to $\frac{3}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{32}$
$\frac{3}{16}$ to $\frac{5}{16}$	[illegible]	$\frac{7}{8}$	$\frac{1}{8}$
$\frac{5}{16}$ to $\frac{1}{2}$	1	1	[illegible]
$\frac{1}{2}$ to $\frac{11}{16}$	$1\frac{1}{4}$	1	[illegible]
$\frac{11}{16}$ to $\frac{7}{8}$	$1\frac{1}{2}$	1	[illegible]

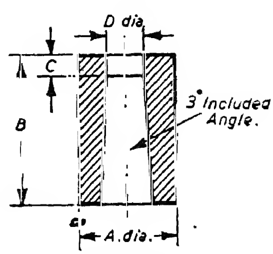


Fig. 20.—Button-die proportions.

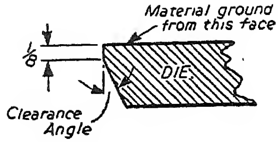


Fig. 21.—Die clearance.

TABLE 3
CLEARANCE IN THOUSANDTHS

Amount ground from Face	$\frac{1}{2}°$	1°	$1\frac{1}{2}°$	2°	$2\frac{1}{2}°$
0·01	0·00009	0·00017	0·00026	0·00035	0·00044
0·02	0·00017	0·00035	0·00052	0·00070	0·00087
0·03	0·00024	0·00052	0·00079	0·00105	0·00131
0·04	0·00038	0·00070	0·00105	0·00140	0·00174
0·05	0·00044	0·00088	0·00131	0·00174	0·00218
0·06	0·00052	0·00105	0·00157	0·00209	0·00262
0·07	0·00061	0·00122	0·00183	0·00244	0·00301
0·08	0·00070	0·00140	0·00210	0·00309	0·00349
0·09	0·00078	0·00157	0·00236	0·00314	0·00393
0·10	0·00087	0·00175	0·00262	0·00349	0·00440
0·11	0·00096	0·00193	0·00288	0·00384	0·00480
0·12	0·00105	0·00210	0·00314	0·00419	0·00524
0·13	0·00113	0·00227	0·00340	0·00454	0·00568
0·14	0·00122	0·00245	0·00367	0·00488	0·00611
0·15	0·00131	0·00263	0·00393	0·00524	0·00655
0·16	0·00142	0·00280	0·00419	0·00558	0·00698
0·17	0·00148	0·00297	0·00455	0·00593	0·00742
0·18	0·00157	0·00315	0·00471	0·00628	0·00786
0·19	0·00166	0·00333	0·00498	0·00663	0·00829
0·20	0·00175	0·00350	0·00524	0·00698	0·00873

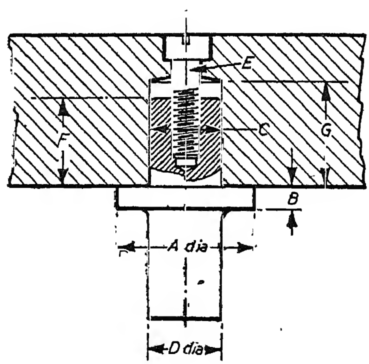


Fig. 22.—Punches held by set screw.

TABLE 4
PUNCHES HELD BY SET SCREW

Dia. D	*A*	*B*	*C*	*E*	*F*	*G*	*H*
$\frac{1}{4}$	[illegible]	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{5}{16}$ Whit.	1	1[illegible]	1[illegible]
$\frac{3}{8}$	[illegible]	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{5}{16}$ Whit.	1	1[illegible]	1[illegible]
$\frac{1}{2}$	[illegible]	$\frac{1}{8}$	[illegible]	$\frac{5}{16}$ Whit.	1	1[illegible]	1[illegible]
$\frac{5}{8}$	[illegible]	$\frac{1}{8}$	[illegible]	[illegible] Whit.	1	1[illegible]	1[illegible]
$\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{8}$	[illegible]	[illegible] Whit.	1	1[illegible]	1[illegible]
$\frac{7}{8}$	1	[illegible]	$\frac{3}{4}$	[illegible] Whit.	1	1[illegible]	1[illegible]
1	$1\frac{1}{8}$	[illegible]	$\frac{3}{4}$	[illegible] Whit.	1	1[illegible]	1[illegible]
$1\frac{1}{4}$	1[illegible]	$\frac{5}{32}$	1	[illegible] Whit.	1	1[illegible]	1[illegible]
$1\frac{1}{2}$	1[illegible]	$\frac{5}{32}$	1	[illegible] Whit.	1	1[illegible]	1[illegible]
$1\frac{3}{4}$	1[illegible]	$\frac{5}{32}$	$1\frac{1}{4}$	[illegible] Whit.	1	1[illegible]	1[illegible]
2	$2\frac{3}{16}$	$\frac{5}{32}$	$1\frac{3}{8}$	$\frac{3}{8}$ Whit.	1	1[illegible]	1[illegible]

STANDARD DIE SETS

Desoutter die sets consist of punchholders and die bases made from 14-ton semi-steel, maintained in alignment by hardened-and-ground steel pillars working in hardened, ground, and lapped steel bushes. Continuous lubrication of the guide pillars is effected by the oil reservoirs fitted to the bushes. (See Tables 5 to 12 and Figs. 23 to 30.)

These die sets offer a clearly set-out basis for a Tool Design Department. They are machined to a high standard of accuracy, and all punchholders and die bases of a given size are interchangeable. Die bases only can be supplied in mild steel at extra cost if desired. These are machined from rolled mild-steel slabs or sheet. All pillar die sets have removable mild-steel screwed shanks.

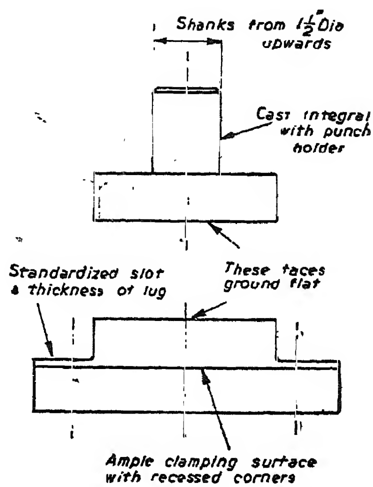


Fig. 23.—Standard plain die set.

Die sets are assembled to the customer's daylight dimensions with guide pins of such a length that they clear the ram at the bottom of the stroke with a reasonable allowance for grinding and, when possible, with bushes of such a length that they do not leave the guide pins at the top of the stroke.

In cases of die sets to be used on long-stroke presses, where the bushes leave the guide pins, means must be taken to prevent the punchholder turning on the shank. If it is preferred to order in terms of shut height instead of daylight, this will read as the daylight when closed plus thickness of punchholder and die base.

Plain Series.—These punchholders and die bases are designed for use in cases where guide pillars are not required. They are cast from the same high-grade materials as for the pillar die sets, i.e. 10 per cent. semi-steel, and the surfaces are finished to the same high standard. The shanks in this series are cast integral with the punchholder, and on this account Desoutter's do not advise a shank diameter of less than $1\frac{1}{2}$ in. where heavy work has to be executed.

TABLE 5.—PLAIN SERIES (Dimension Table in Inches)

Cat. No.	*Thickness of Punchholder and Base*		*Die Space*	*Approx. Weight in lb. of Light-type Die Set Complete*
	Light	*Heavy*		
1P	1	$1\frac{1}{4}$	4×3	13
2P	$1\frac{1}{4}$	$1\frac{1}{2}$	5×4	21
4P	$1\frac{1}{2}$	2	7×5	40
6P	$1\frac{3}{4}$	$2\frac{1}{4}$	9×7	75
8P	2	$2\frac{1}{2}$	12×9	137
10P	$2\frac{1}{4}$	$2\frac{3}{4}$	16×12	255
4LP	$1\frac{1}{4}$	$1\frac{3}{4}$	7×3	24
6LP	$1\frac{1}{2}$	2	9×4	40
8LP	$1\frac{3}{4}$	$2\frac{1}{2}$	12×5	71
10LP	2	$2\frac{3}{4}$	16×6	119

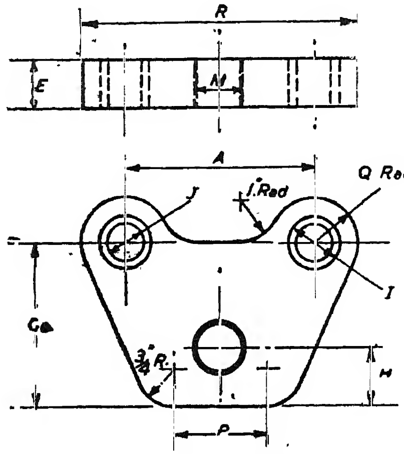


Fig. 24.—Standard die set, V-type punchholder—type V tops.

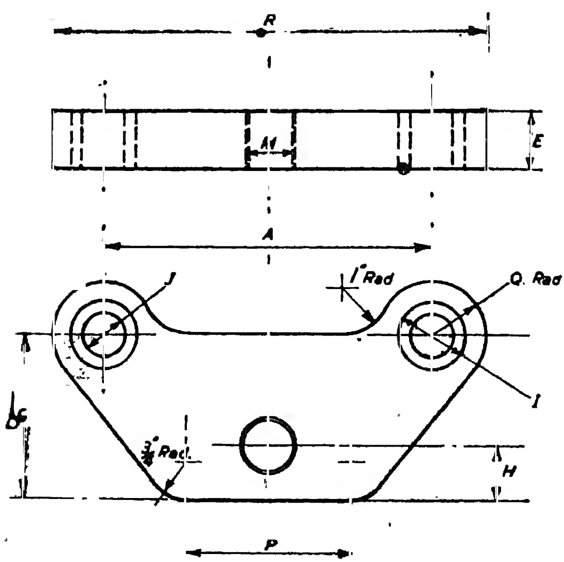


Fig. 25.—V-type punchholder, type LV and MV tops.

Press Tool Classification.—Most press tools may be classified under one of the following headings:

(1) Press tools that act upon the metal by shearing or cutting it.

(2) Tools that bend and form the metal, and in general manipulate it into desired shapes.

(3) Tools that have their main use in assembly work.

In the first class there are the single-operation tools and the complicated types. Of the single-operation type there are the simple tool for cutting blanks and the

TABLE 6.—V-TYPE PUNCHHOLDERS—TYPE V TOPS
(Dimension Table in Inches)

Cat. No.	*A*	*E*		*G*	*H*	*I*	*J*	*M Std. Whit.*	*P*	*Q*	*R*
		Light	*Heavy*								
1V	4	1	1[illegible]	$3\frac{5}{16}$	1[illegible]	$1\frac{1}{8}$	$\frac{3}{4}$	1	2	$\frac{15}{16}$	5[illegible]
2V	5	1[illegible]	1[illegible]	$4\frac{7}{16}$	1[illegible]	$1\frac{3}{8}$	$\frac{7}{8}$	1	2[illegible]	$1\frac{1}{8}$	7[illegible]
3V	6	1[illegible]	$1\frac{3}{4}$	5	1[illegible]	1[illegible]	1	1	2[illegible]	$1\frac{1}{4}$	$8\frac{1}{2}$
4V	7	1[illegible]	2	$5\frac{9}{16}$	$2\frac{1}{8}$	1[illegible]	$1\frac{1}{8}$	1	3[illegible]	1[illegible]	9[illegible]
5V	8	1[illegible]	$2\frac{1}{8}$	$6\frac{9}{16}$	$2\frac{5}{8}$	1[illegible]	1[illegible]	1[illegible]	4[illegible]	1[illegible]	10[illegible]
6V	9	1[illegible]	2[illegible]	7[illegible]	$3\frac{1}{8}$	1[illegible]	$1\frac{1}{4}$	1[illegible]	$4\frac{1}{2}$	1[illegible]	12
7V	10	1[illegible]	$2\frac{3}{8}$	8[illegible]	$3\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	5	1[illegible]	13
8V	12	2	$2\frac{1}{2}$	9[illegible]	$4\frac{1}{8}$	2	1[illegible]	$1\frac{1}{2}$	6	1[illegible]	$15\frac{1}{2}$
9V	14	$2\frac{1}{8}$	$2\frac{5}{8}$	11[illegible]	5[illegible]	2	1[illegible]	$1\frac{1}{2}$	6	1[illegible]	$17\frac{1}{2}$
10V	16	2[illegible]	2[illegible]	$12\frac{1}{4}$	5[illegible]	2	1[illegible]	$1\frac{1}{2}$	8	1[illegible]	$19\frac{1}{2}$
11V	18	2[illegible]	3[illegible]	15	6[illegible]	2[illegible]	$1\frac{3}{4}$	$1\frac{1}{2}$	9	2[illegible]	$22\frac{1}{2}$
12V	24	$2\frac{3}{4}$	$3\frac{1}{2}$	$19\frac{1}{8}$	8[illegible]	2[illegible]	2	$1\frac{1}{2}$	11	$2\frac{3}{8}$	$28\frac{3}{4}$

TABLE 7.—V-TYPE PUNCHHOLDERS—TYPE LV AND MV TOPS
(Dimension Table in Inches)

Cat. No.	*A*	*E*		*G*	*H*	*I*	*J*	*M Std. Whit.*	*P*	*Q*	*R*
		Light	*Heavy*								
4LV	7	$1\frac{1}{4}$	1[illegible]	$3\frac{7}{16}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{7}{8}$	1	$3\frac{1}{2}$	$1\frac{1}{8}$	9[illegible]
5LV	8	1[illegible]	1[illegible]	4	1[illegible]	$1\frac{1}{2}$	1	1	$4\frac{1}{2}$	1[illegible]	10[illegible]
6LV	9	$1\frac{1}{2}$	2	$4\frac{9}{16}$	1[illegible]	1[illegible]	$1\frac{1}{8}$	1	$4\frac{1}{2}$	$1\frac{3}{8}$	11[illegible]
7LV	10	$1\frac{5}{8}$	2[illegible]	$5\frac{1}{16}$	1[illegible]	1[illegible]	1[illegible]	1	5	1[illegible]	12[illegible]
8LV	12	$1\frac{3}{4}$	2[illegible]	$5\frac{5}{8}$	2[illegible]	1[illegible]	1[illegible]	$1\frac{1}{4}$	6	1[illegible]	15
9LV	14	2	2[illegible]	$6\frac{1}{8}$	2[illegible]	1[illegible]	1[illegible]	1[illegible]	6	1[illegible]	17
10LV	16	2	2[illegible]	6[illegible]	2[illegible]	2	$1\frac{1}{2}$	1[illegible]	8	1[illegible]	19[illegible]
10MV	16	2	2[illegible]	9[illegible]	$4\frac{1}{8}$	2	$1\frac{1}{2}$	[illegible]	8	1[illegible]	19[illegible]
11LV	18	2[illegible]	3	8	3[illegible]	$2\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{2}$	9	2[illegible]	22[illegible]
12LV	24	2[illegible]	$3\frac{1}{4}$	$10\frac{1}{8}$	$4\frac{1}{3}$	$2\frac{3}{4}$	2	$1\frac{1}{2}$	11	$2\frac{3}{8}$	$28\frac{3}{4}$

simple piercing tool. The usual method of ensuring correct alignment of punch and die is to fit a stripper of reasonable proportion and rigid enough to act as a guide to pilot the punch into the die as well as to act in its own capacity as a stripper for the material.

An example of a multi-operation tool is one which pierces and blanks, pierces and crops, pierces, plunges and blanks, or a multi-piercing tool where all the holes are not pierced in one stroke. These are sometimes referred to as perforating tools. There are also tandem tools, so called because they cut two sets of blanks and piercings at the same time. Any press tool that makes use of a follow-on or progressive layout can be classed as multi-operational.

TABLE 8.—REAR PILLAR DIE SETS—TYPE R (Dimension Table in Inches)

Cat. No.	*Length in Inches*	*Width in Inches*	*A*	*B*	*C*	*D*	*E and F*		*G*	*H*	*J*	*K*	*M Std. Whit.*	*N*	*Bush Length Range*	*Pin Length Range*
							Light	*Heavy*								
1R	4	3	4	$5\frac{3}{4}$	7	$4\frac{5}{8}$	1	$1\frac{1}{4}$	$3\frac{11}{16}$	$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	1	$\frac{1}{2}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
2R	5	4	5	$6\frac{3}{4}$	8	$5\frac{15}{16}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$4\frac{13}{16}$	2	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{5}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
3R	6	$4\frac{1}{2}$	6	$7\frac{3}{4}$	9	$6\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$5\frac{3}{8}$	$2\frac{1}{4}$	1	$\frac{3}{4}$	1	$\frac{5}{8}$	2 to $3\frac{1}{2}$	$2\frac{1}{2}$ to 7
4R	7	5	7	$9\frac{1}{4}$	11	$7\frac{5}{16}$	$1\frac{1}{2}$	2	$5\frac{15}{16}$	$2\frac{1}{2}$	$1\frac{1}{8}$	1	1	$\frac{3}{4}$	2 to $3\frac{1}{2}$	3 to 7
5R	8	6	8	$10\frac{1}{4}$	12	$8\frac{5}{16}$	$1\frac{5}{8}$	$2\frac{1}{8}$	$6\frac{15}{16}$	3	$1\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{3}{4}$	2 to $3\frac{1}{2}$	3 to 7
6R	9	7	9	$11\frac{1}{4}$	13	$9\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{4}$	8	$3\frac{1}{2}$	$1\frac{1}{4}$	1	$1\frac{1}{4}$	$\frac{7}{8}$	$2\frac{1}{2}$ to 4	3 to 7
7R	10	8	10	$12\frac{1}{4}$	14	$10\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{3}{8}$	9	4	$1\frac{1}{4}$	1	$1\frac{1}{4}$	$\frac{7}{8}$	3 to $4\frac{1}{2}$	3 to 7
8R	12	9	12	$14\frac{1}{4}$	16	$11\frac{7}{8}$	2	$2\frac{1}{2}$	$10\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	3 to $4\frac{1}{2}$	3 to 7
9R	14	11	14	$16\frac{1}{4}$	18	$13\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{5}{8}$	$12\frac{1}{8}$	$5\frac{1}{2}$	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	3 to $4\frac{1}{2}$	3 to 7
10R	16	12	16	$18\frac{1}{4}$	20	$14\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$13\frac{1}{8}$	6	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	3 to $4\frac{1}{2}$	3 to 7
11R	18	14	18	$20\frac{1}{4}$	22	$17\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{4}$	$15\frac{3}{8}$	7	$1\frac{3}{4}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	$3\frac{1}{2}$ to 5	$4\frac{1}{2}$ to 8
12R	24	18	24	$26\frac{1}{4}$	28	$21\frac{7}{8}$	$2\frac{3}{4}$	$3\frac{1}{2}$	$19\frac{1}{2}$	9	2	1	$1\frac{1}{2}$	1	4 to 5	5 to 8

TABLE 9.—REAR PILLAR STANDARDISED DIE SETS—TYPE RL AND RM (Dimension Table in Inches)

Cat. No.	*Length in Inches*	*Width in Inches*	*A*	*B*	*C*	*D*	*E and F*		*G*	*H*	*J*	*K*	*M Std. Whit.*	*N*	*Bush Length Range*	*Pin Length Range*
							Light	*Heavy*								
4RL	7	3	7	$8\frac{3}{4}$	10	$4\frac{15}{16}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$3\frac{13}{16}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{5}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
5RL	8	$3\frac{1}{2}$	8	$9\frac{3}{4}$	11	$5\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{7}{8}$	$4\frac{3}{8}$	$1\frac{3}{4}$	1	$\frac{3}{4}$	1	$\frac{3}{4}$	2 to $3\frac{1}{2}$	$2\frac{1}{2}$ to 7
6RL	9	4	9	$11\frac{1}{4}$	13	$6\frac{5}{16}$	$1\frac{1}{2}$	2	$4\frac{15}{16}$	2	$1\frac{1}{8}$	1	1	$\frac{3}{4}$	2 to $3\frac{1}{2}$	3 to 7
7RL	10	$4\frac{1}{2}$	10	$12\frac{1}{4}$	14	$6\frac{13}{16}$	$1\frac{5}{8}$	$2\frac{1}{4}$	$5\frac{7}{16}$	$2\frac{1}{4}$	$1\frac{1}{8}$	1	1	$\frac{7}{8}$	2 to $3\frac{1}{2}$	3 to 7
8RL	12	5	12	$14\frac{1}{4}$	16	$7\frac{1}{2}$	$1\frac{3}{4}$	$2\frac{1}{2}$	6	$2\frac{1}{2}$	$1\frac{1}{4}$	1	$1\frac{1}{4}$	$\frac{7}{8}$	$2\frac{1}{2}$ to 4	3 to 7
9RL	14	$5\frac{1}{2}$	14	$16\frac{1}{4}$	18	8	$1\frac{7}{8}$	$2\frac{5}{8}$	$6\frac{1}{2}$	$2\frac{3}{4}$	$1\frac{1}{4}$	1	$1\frac{1}{4}$	$\frac{7}{8}$	$2\frac{1}{2}$ to 4	3 to 7
10RL	16	6	16	$18\frac{1}{4}$	20	$8\frac{7}{8}$	2	$2\frac{3}{4}$	$7\frac{1}{8}$	3	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	3 to $4\frac{1}{2}$	3 to 7
10RM	16	9	16	$18\frac{1}{4}$	20	$11\frac{7}{8}$	2	$2\frac{3}{4}$	$10\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{1}{2}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	3 to $4\frac{1}{2}$	3 to 7
11RL	18	7	18	$20\frac{1}{4}$	22	$10\frac{1}{2}$	$2\frac{1}{4}$	3	$8\frac{3}{8}$	$3\frac{1}{2}$	$1\frac{3}{4}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	$3\frac{1}{2}$ to 5	$4\frac{1}{2}$ to 8
12RL	24	9	24	$26\frac{1}{4}$	28	$12\frac{7}{8}$	$2\frac{1}{2}$	$3\frac{1}{4}$	$10\frac{1}{2}$	$4\frac{1}{2}$	2	1	$1\frac{1}{2}$	1	4 to 5	5 to 8

The compound tool accomplishes the operation of piercing and blanking at one stroke, unlike the follow-on tools which pierce and then blank. Other types are press tools for bending and embossing.

A dinking die is a hollow punch with a sharp cutting edge shaped to coincide with the contour of the blank it is desired to cut. Such dies are usually used on non-metallic materials, such as paper, cloth, leather, and certain of the plastics.

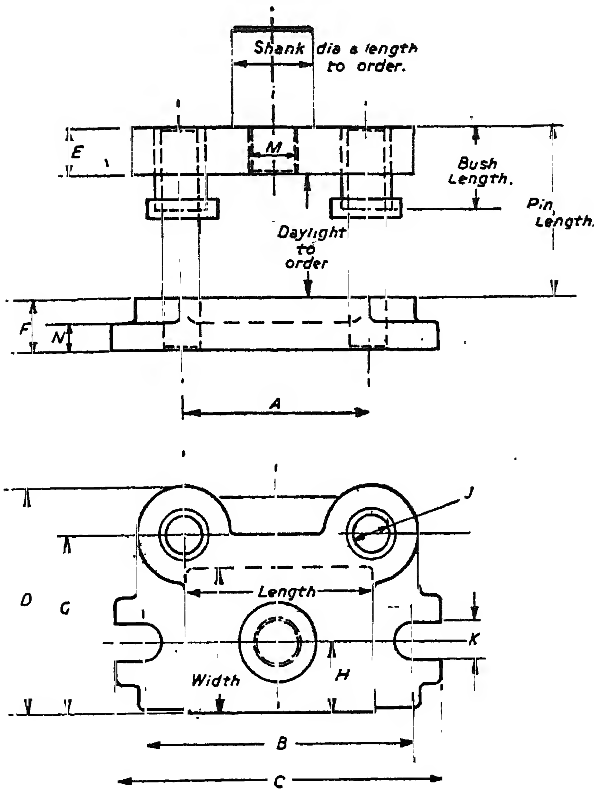


Fig. 26.—Rear pillar die sets, type R.

Straightening Rolls.—These are used for strip straightening in press work. The rolls are carried in an adjustable holder so that each roll can be adjusted for height and then locked into position in the body of the apparatus, which is usually hinged to open like a book for loading the strip. They are mounted on easy-running bearings so that they turn with the motion of the strip through them. They are not usually driven, as the strip is pulled through them by means of the automatic feed gear of the press. They are not usually used with thick strip, as their main use is with coiled stock on multiple-operation tooling for long runs at high speed.

Power Press Details.—The power press, like the hand press, depends a great deal upon the design and functioning of the special tools for each particular piece part, but in addition to this the over-all efficiency of the press shop can be greatly increased by the intelligent handling of the presses as a whole.

The shop layout plays an important part in the efficient running of any machine tool. In the case of the power press, this depends upon the type of work encoun-

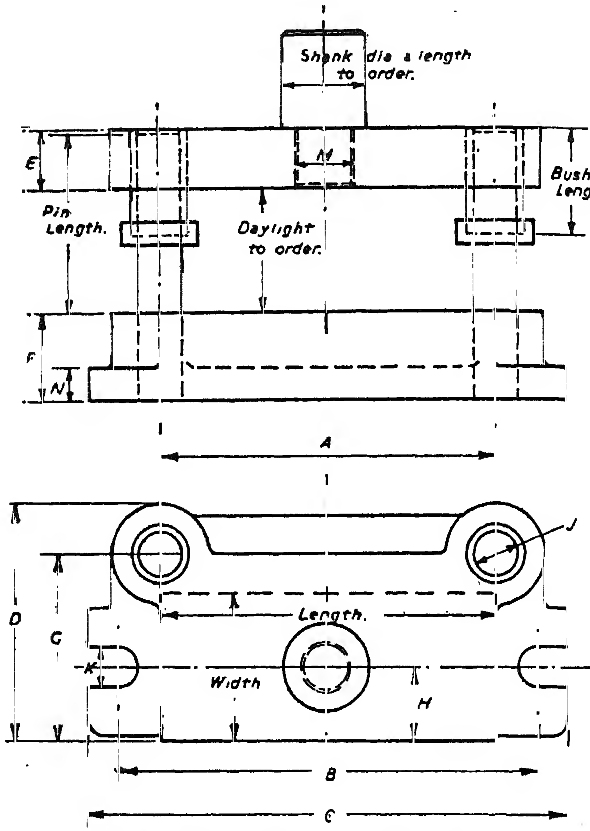


Fig. 27.—Rear pillar die set, types RL and RM.

tered and the number of presses installed. A large press shop can be efficiently laid out, as shown in Fig. 31, with the presses arranged in rows, with the rows staggered. Thus components requiring two or more pressing operations can be run successfully by setting succeeding tools on the press to the rear of that upon which the previous operation is carried out. Simple chutes from the rear of the press carry the completed articles to the next operator.

For a small press shop, consisting of one line of presses, an admirable arrangement is to incline the presses in rows so that strips being fed upon any press do

TABLE 10.—DIAGONAL PILLAR DIE SETS—TYPE DS (Dimension Table in Inches)

Cat. No.	*Length in Inches*	*Width in Inches*	*A*	*B*	*C*	*D*	*E and F*		*J*	*I*	*M Std. Whit.*	*N*	*O*	*Bush Length Range*	*Pin Length Range*
							Light	*Heavy*							
D5S	$2\frac{1}{2}$	$2\frac{1}{2}$	5	$4\frac{1}{4}$	$5\frac{3}{8}$	$5\frac{3}{8}$	1	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
D6S	$3\frac{1}{4}$	$3\frac{1}{4}$	6	5	$6\frac{1}{8}$	$6\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
D7S	4	4	7	$5\frac{3}{4}$	$7\frac{1}{8}$	$7\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
D8S	$4\frac{1}{2}$	$4\frac{1}{2}$	8	$6\frac{1}{2}$	8	8	$1\frac{1}{4}$	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{5}{8}$	1	2 to 3	$2\frac{1}{2}$ to 7
D9S	$5\frac{1}{4}$	$5\frac{1}{4}$	9	$7\frac{1}{4}$	$8\frac{3}{4}$	$8\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{3}{4}$	1	$\frac{7}{8}$	1	$\frac{3}{4}$	1	2 to 3	$2\frac{1}{2}$ to 7
D10S	6	6	10	8	$9\frac{7}{8}$	$9\frac{7}{8}$	$1\frac{1}{2}$	2	1	$\frac{7}{8}$	1	$\frac{3}{4}$	1	2 to $3\frac{1}{2}$	3 to 7
D12S	$7\frac{1}{4}$	$7\frac{1}{4}$	12	$9\frac{1}{2}$	$11\frac{1}{8}$	$11\frac{1}{8}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{7}{8}$	$1\frac{1}{8}$	2 to $3\frac{1}{2}$	3 to 7
D14S	$8\frac{1}{2}$	$8\frac{1}{2}$	14	$10\frac{3}{4}$	$12\frac{7}{8}$	$12\frac{7}{8}$	$1\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{8}$	$2\frac{1}{2}$ to $3\frac{1}{2}$	3 to 7
D16S	10	10	16	13	$14\frac{5}{8}$	$14\frac{5}{8}$	2	$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	3 to 4	3 to 7
D18S	11	11	18	14	$16\frac{5}{8}$	$16\frac{5}{8}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	$3\frac{1}{2}$ to $4\frac{1}{2}$	$4\frac{1}{2}$ to 7
D24S	15	15	24	18	$21\frac{5}{8}$	$21\frac{5}{8}$	$2\frac{1}{2}$	$3\frac{1}{4}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$	1	$1\frac{1}{2}$	4 to 5	5 to 8

TABLE 11.—DIAGONAL PILLAR STANDARDISED DIE SETS—TYPE DL (Dimension Table in Inches)

Cat. No.	*Length in Inches*	*Width in Inches*	*A*	*B*	*C*	*D*	*E and F*		*J*	*L*	*M Std. Whit.*	*N*	*O*	*Bush Length Range*	*Pin Length Range*
							Light	*Heavy*							
D5L	3	2	5	$4\frac{3}{4}$	6	$4\frac{1}{2}$	1	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
D6L	4	$2\frac{3}{4}$	6	$5\frac{3}{4}$	$6\frac{3}{4}$	$5\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
D7L	$4\frac{1}{2}$	3	7	$6\frac{1}{4}$	8	6	$1\frac{1}{8}$	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$ to 3	$2\frac{1}{2}$ to 7
D8L	$5\frac{1}{4}$	$3\frac{1}{2}$	8	$7\frac{1}{4}$	9	$6\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{5}{8}$	1	$\frac{7}{8}$	1	$\frac{5}{8}$	1	2 to 3	$2\frac{1}{2}$ to 7
D9L	6	4	9	8	10	$7\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{3}{4}$	1	$\frac{7}{8}$	1	$\frac{3}{4}$	1	2 to 3	$2\frac{1}{2}$ to 7
D10L	$6\frac{3}{4}$	$4\frac{1}{2}$	10	$8\frac{3}{4}$	11	$8\frac{3}{8}$	$1\frac{1}{2}$	2	$1\frac{1}{8}$	1	1	$\frac{3}{4}$	1	2 to $3\frac{1}{2}$	3 to 7
D12L	$8\frac{1}{2}$	$5\frac{1}{2}$	12	$10\frac{3}{4}$	$12\frac{3}{4}$	$9\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{7}{8}$	$1\frac{1}{8}$	2 to $3\frac{1}{2}$	3 to 7
D14L	10	7	14	$12\frac{1}{4}$	$14\frac{1}{2}$	11	$1\frac{7}{8}$	$2\frac{3}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{8}$	$2\frac{1}{2}$ to $3\frac{1}{2}$	3 to 7
D16L	12	$7\frac{1}{2}$	16	15	$16\frac{7}{8}$	$11\frac{7}{8}$	2	$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	3 to 4	3 to 7
D18L	13	$8\frac{1}{2}$	18	16	19	$13\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	$3\frac{1}{2}$ to $4\frac{1}{2}$	$4\frac{1}{2}$ to 7
D24L	$17\frac{1}{2}$	12	24	$20\frac{1}{2}$	$24\frac{1}{2}$	$18\frac{1}{8}$	$2\frac{1}{2}$	$3\frac{1}{4}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$	1	$1\frac{1}{2}$	4 to 5	5 to 8

not interfere with the operations of adjacent presses; also with rear-exit tools chutes can be arranged so that a follow up is obtainable along the row (Fig. 32).

Many alternative arrangements are possible to suit the particular type of component with which the shop is mainly intended to deal. For instance, using follow-on tools with strip material and gripper feed (or front-to-back feed rolls), a line of presses can be arranged so that one gangway serves for delivery of strip material and the gangway to the rear of the presses serves for the collection of finished components (Fig. 33).

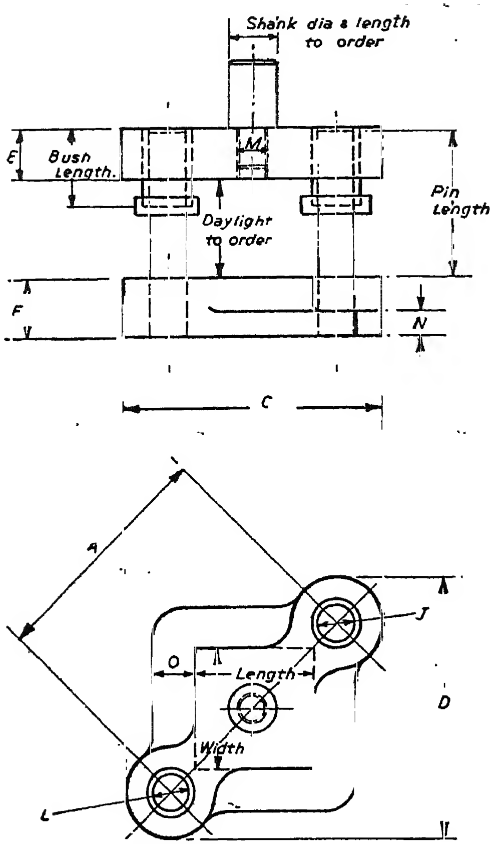


Fig. 28.—Diagonal pillar die sets, type DS.

Apparatus for Use with Strip Material.—When dealing with strip material (supplied in coils), it is of course desirable to have continuous operation.

The first essential for efficient continuous runs is a good coil stand. Such a coil stand should be capable of adjustment for internal diameter of the coil and width of strip. It should also be simple to load. A further refinement is to have an adjustment whereby the coil can be tilted when using the press in the inclined position.

A great help with strip work is to install straightening rolls to remove kinks, etc., from the coils as the strip is fed from the roll. Straightening rolls have two important influences upon the action of the tools. The first is that kinked strip is avoided. Thus the spacing of operations in follow-on tools is correctly maintained. Secondly, if the straightening rolls are arranged with the first few rolls rather more out of line than is normally the practice, a certain amount of molecular agitation is imparted to the strip, which sometimes makes all the difference between a successful production and failure due to excessive work hardening before the final stage of the follow-on tools is reached. Such molecular agitation tends to offset to a slight extent the age hardening which occurs when strip brass has been stored coiled for some considerable period.

Mechanical Feed.—A common type of mechanical feed is the feed roll (Fig. 34). This consists of a pair of feed rolls set at either end of the table (or in some

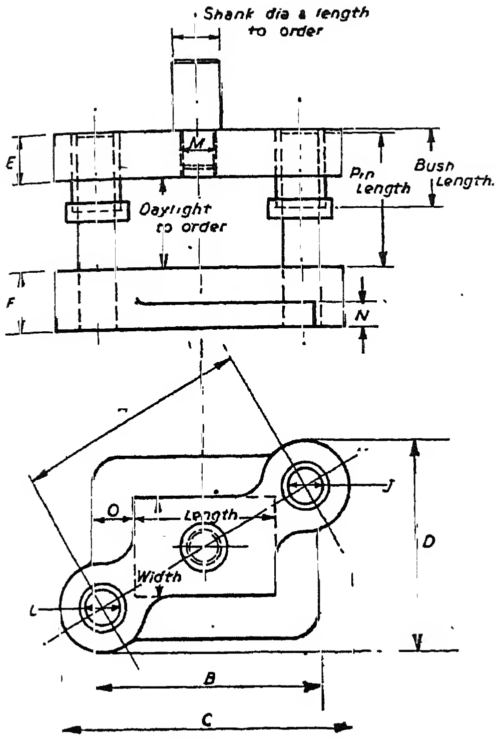


Fig. 29.—Diagonal pillar die set, type DL.

cases at the back and front of the table, as already mentioned, thus feeding the strip between the columns of the press), which are driven from the crankshaft by means of an adjustable crank-pin fitted in a slotted disc. The stroke of these rolls can be varied to suit the particular length of feed required. Arrangements are made whereby the gripping pressure on the strip is released as the tools close, so that pilots in the tools take control of the strip during the action of the tool.

Another type of feed is the gripper feed (Fig. 35). This consists of a pair of feed bars on each side of the table, which are actuated by a mechanism which causes them to come together and grip the strip material, then advance by an adjustable amount. They then open and return to their initial position in order to feed forward another bit of stock.

A simpler type of feed device is the pusher feed (Fig. 36), but the application of this feed is rather limited, as it

TABLE 12.—PUNCHES

Dia. D	*A*	*B*	*C*	*E*
0–$\frac{1}{4}$	$\frac{5}{16}$	$\frac{21}{64}$	$\frac{3}{32}$	$\frac{5}{8}$
$\frac{5}{16}$	$\frac{7}{16}$	$\frac{29}{64}$	$\frac{3}{32}$	$\frac{5}{8}$
$\frac{3}{8}$	$\frac{1}{2}$	$\frac{33}{64}$	$\frac{3}{32}$	$\frac{5}{8}$
$\frac{7}{16}$	$\frac{9}{16}$	$\frac{37}{64}$	$\frac{3}{32}$	$\frac{5}{8}$
$\frac{1}{2}$	$\frac{5}{8}$	$\frac{41}{64}$	$\frac{3}{32}$	$\frac{5}{8}$
$\frac{5}{8}$	$\frac{3}{4}$	$\frac{49}{64}$	$\frac{3}{32}$	$\frac{5}{8}$
$\frac{3}{4}$	$\frac{7}{8}$	$\frac{57}{64}$	$\frac{1}{8}$	$\frac{3}{4}$
1	$1\frac{1}{8}$	$1\frac{9}{64}$	$\frac{1}{8}$	$\frac{3}{4}$

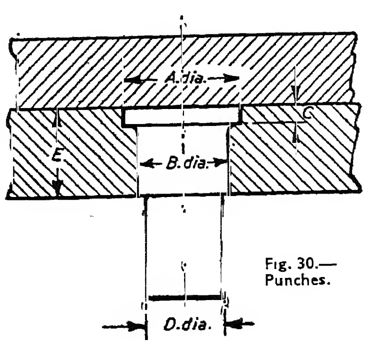


Fig. 30.—Punches.

TABLE 13.—BLANKING PRESSURE PER INCH LENGTH FOR MILD STEEL
(Shear stress taken as 20 tons/sq. in.)

B.W.G.	*S.W.G.*	*Thickness*	*Blanking Pressure/in.*
4	—	0·238	10,660
—	4	0·232	10,400
5	—	0·220	9,856
—	5	0·212	9,497
6	—	0·203	9,095
—	6	0·192	8,602
7	—	0·180	8,065
—	7	0·176	7,882
8	—	0·165	7,392
—	8	0·160	7,168
9	—	0·148	6,631
—	9	0·144	6,452
10	—	0·134	6,003
—	10	0·128	5,735
11	—	0·120	5,376
—	11	0·116	5,198
12	—	0·109	4,883
—	12	0·104	4,659
13	—	0·095	4,256
—	13	0·092	4,122
14	—	0·083	3,718
—	14	0·080	3,584
15	15	0·072	3,225
16	—	0·065	2,912
—	16	0·064	2,867
17	—	0·058	2,598
—	17	0·056	2,509
18	—	0·049	2,196
—	18	0·0485	2,173
19	—	0·042	1,881
—	19	0·040	1,793
—	20	0·036	1,613
20	—	0·035	1,568
21	21	0·032	1,433
22	—	0·030	1,344
—	22	0·028	1,254
23	—	0·025	1,120
—	23	0·024	1,075
24	—	0·022	985·6
25	25	0·020	896·0
26	26	0·018	806·5
27	27	0·016	716·8
28	28	0·014	627·2
29	29	0·0131	586·9
30	30	0·012	537·6
—	31	0·011	492·8
31	—	0·010	448·0
—	32	0·01080	483·9
32	—	0·009	403·2
—	33	0·010	448·0
33	—	0·008	358·4
34	—	0·007	313·6
—	34	0·009	403·2
—	35	0·008	358·4
35	—	0·005	224·1
—	36	0·007	313·6
36	—	0·004	179·3

works best with fairly thick strip of about 18 S.W.G. This feed functions as follows :

A small slide is driven backwards and forwards to an extent equal to the amount of stock required. Upon this slide is mounted a gripping device which will push the strip forward but will not grip on the return stroke. This strip is pushed forward between the jaws of a similar device, which allows the strip to feed forward but will not let it return. Thus with each oscillation of the slide an adjustable amount of strip is fed.

Disposal of Scrap Strip.—In the majority of cases after the strip has been fed through the tool it emerges on the other side in the form of a perforated strip

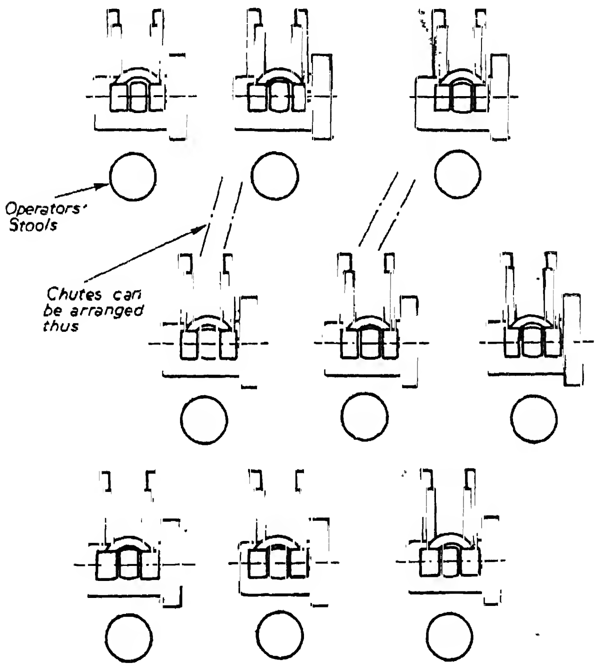


Fig. 31.—Arrangement of presses in a large press shop.

of swarf. Much time can be saved if arrangements are made upon the press for the disposal of this scrap swarf. There are two main methods of scrap disposal, the most popular of which is the scrap chopper. This is essentially a small guillotine fitted to the end of the press table and actuated by an eccentric directly mounted upon the press shaft.

An alternative method of scrap disposal is to fit a scrap coil attachment to the press ; this is usually driven by an extension of the roll-feed drive shaft.

Lubrication.—The lubrication of continuous-action tooling is of great importance as, even with very simple follow-on tools, much needless wear takes place if strip is run through the tool without adequate lubrication or without any lubrication whatsoever.

A simple strip oiling gear is shown in Fig. 37. The drip can should be adjusted to keep approximately ¼ in. of lubricant in the upper trough.

Lubricant which has collected in the lower trough should be filtered before returning it to the drip can, which should be kept covered, as dust mixed with the lubricant forms an abrasive paste which is injurious to the tool.

From the foregoing we see that for a super high-speed operation from strip material the set-up is in the manner of Fig. 38, in which the strip is fed from the feed coil to the straightening rolls, through the oiling and wiping gear, then

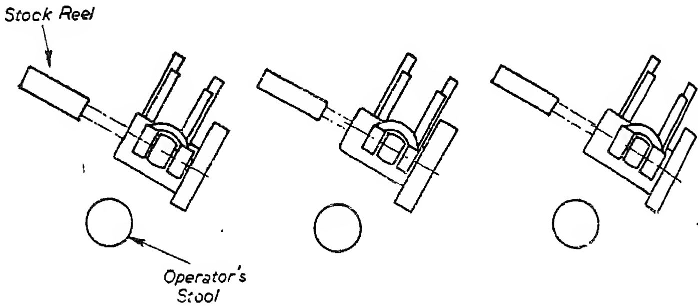


Fig. 32.—Special arrangement for a small press shop.

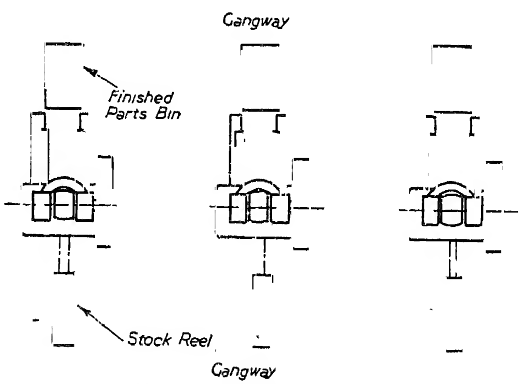


Fig. 33.—Arrangement for high production with follow-on tools.

through the tool to the second pair of feed rolls, and then through the scrap chopper into the scrap box.

An electric warning device can be fitted if desired to warn the operator that the strip has worn out and needs replenishing.

Handling Small Pots.—All press operations, however, are not covered by the use of continuous strip. When dealing with small pots for re-drawing operations some form of simple chute can speed up the process of re-drawing and at the same time make the operation much safer from the operator's point of view.

A very simple guide attached to the tool (as shown in Fig. 39) enables pots to be hand fed by pushing the outer pot along the guide, and so sliding the whole

line of pots along until the first pot rests in the vee guide and is centred beneath the punch.

As the pots do not return through the die but are fed away beneath the press by a chute, it can be seen that it is a simple matter to push a further pot into place before the punch again descends.

If desired the chute can be given an upward curve so that pots are fed along the horizontal portion by the force of gravity.

The Gang Press.—For very high production of pots which need a succession of draws and are capable of running through without inter-stage annealing, a special type of press has been evolved termed the gang press. This press is equipped with feed plates which are brought together to grip the work as the

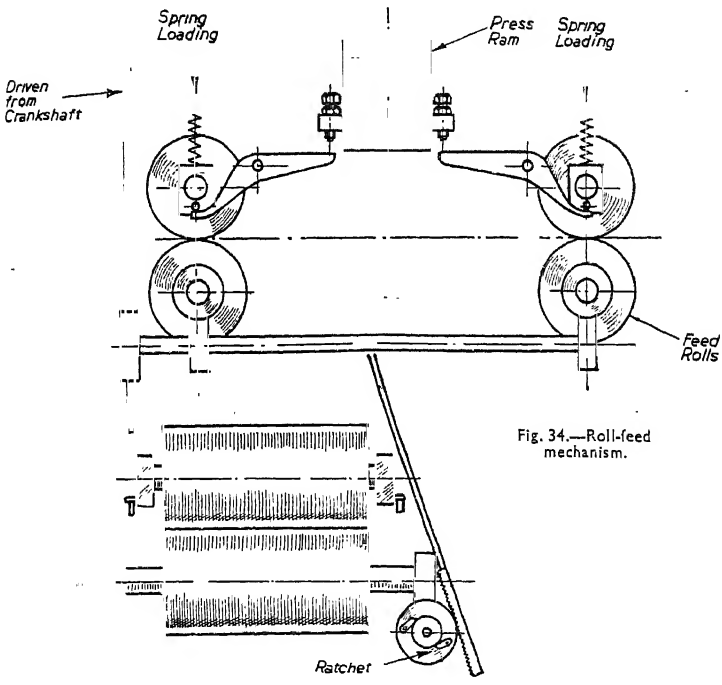


Fig. 34.—Roll-feed mechanism.

punch ascends, move forward while the punch is at the top of its stroke, and release the work before the punches again descend. While the punches are down they return to the starting-position in order to advance a further set of work-pieces along the dies.

With this type of press a hopper feed is essential, as a constant supply of work-pieces must be maintained at the loading-position.

Presses of this type can continue without stoppage so long as the supply of work-pieces is kept up at the rate of about 100 per minute.

Use of Inclinable Press.—Power presses are often constructed so that the main frame of the press rests in a cradle and is adjustable to operate over an angle of 30 to 45 degrees from the vertical. This is to enable dies to be cleared of finished components by gravity action. A typical example of this type of operation is

indicated in Fig. 40. Here we have a guillotined blank which is to have an aperture blanked from the centre, and notches pierced in the ends and at the corners, as shown.

There are many ways of doing this operation, but perhaps the quickest in operation is to design the tool for an inclined press. The blank is fed in the front chutes and slides by its weight to the stop at the back of the tool. The press descends and a trip on the top tool engages with a snap action, which retracts the back stop and so allows the blank to slide out at the back of the press when the punch ascends. The operator then resets the stop and loads a further blank. Thus the operator has to contend only with the loading of the tool; the unloading and disposal of the finished product and also the blankings are automatic. If we assume for the purpose of illustration that the piercings are larger than the hole in the press bed, we note that by the addition of a further sheet-metal chute (Fig. 40) the required components will slide into another box and so will be automatically sorted.

A further instance of inclined-press operation is that of producing shallow pots (as shown in Fig. 41).

The usual difficulty experienced with such shallow pots is that they are not

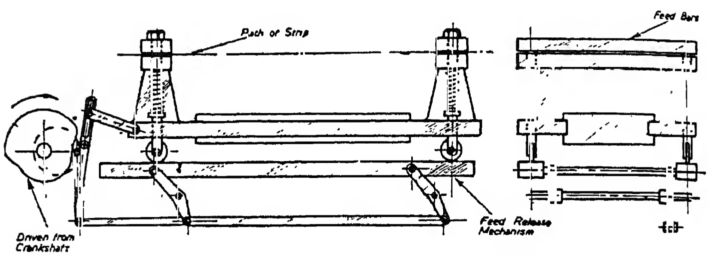


Fig. 35.—Gripper feed mechanism.

deep enough to be pulled out of the tool by the progression of the strip and are rather awkward to eject by compressed air.

By using a high stripper tool and inclined press the operation is simplified and the action is as follows. After completion of the stroke the strip is carried up with the punch and so is held clear of the pot while it slides out at the back of the tool.

When the punch finally leaves the strip the pot has had time to get clear, and so the strip in returning to the die face does not become entangled with the work-piece.

The main points to bear in mind when considering power-press utilisation are: How will the tool be loaded? How will the finished job be disposed of? How will the operations follow up and smooth arrangements be made for chutes, etc.?

The components and scrap choppings should be led into a different box, so that the rather tedious work of sorting jobs from scrap in a heap beneath the press is avoided. Furthermore, care, coupled with cleanliness and correct lubrication, can do much to increase the life of the very costly tools with which presses are equipped. Finally, in the handling of the machines, i.e. disposition in the machine-shop line, shop layout, transport facilities, etc., have a great bearing upon the efficient usage of individual machines and the shops as a whole.

The Hydraulic Press.—The chief advantages of the hydraulic press are the ability to exert pressure uniformly throughout any desired portion of the stroke, and to maintain such pressure for any length of time which may be necessary, together with simplicity of operation and maintenance due to the small number of moving parts. These parts, however, must be kept in good condition if maximum efficiency is to be maintained, a fact which it is to be feared is not always fully appreciated.

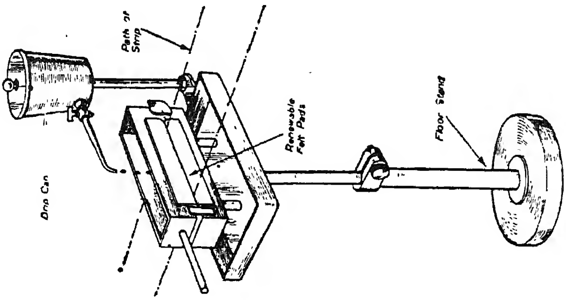


Fig. 37.—Strip oiling and cleaning apparatus.

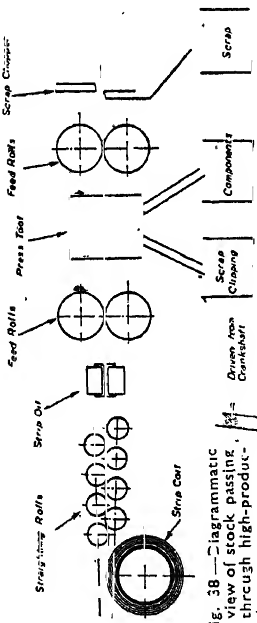


Fig. 38.—Diagrammatic view of stock passing through high-production press.

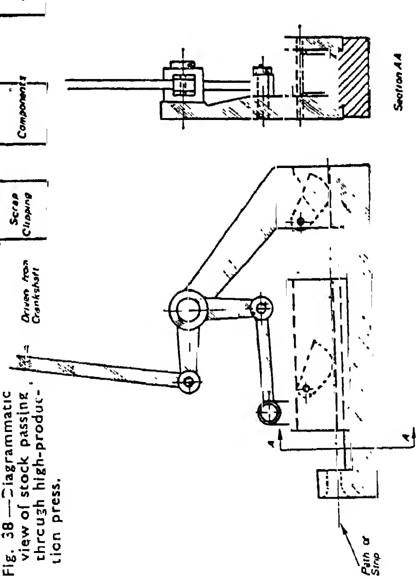


Fig. 35.—Pusher feed mechanism.

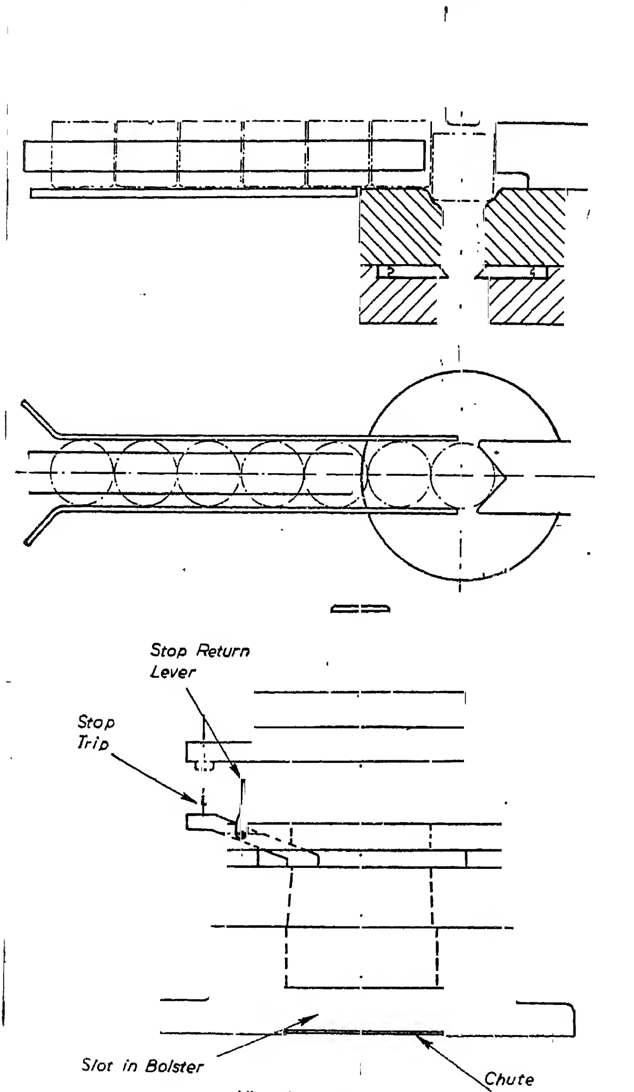


Fig. 39.—Simple chute to assist the loading of pots.

Types of Hydraulic Presses.—There is an almost endless variety of types of presses, ranging from the complex machines capable of exerting powers of thousands of tons used in the forging, bending and extruding of metals, to the

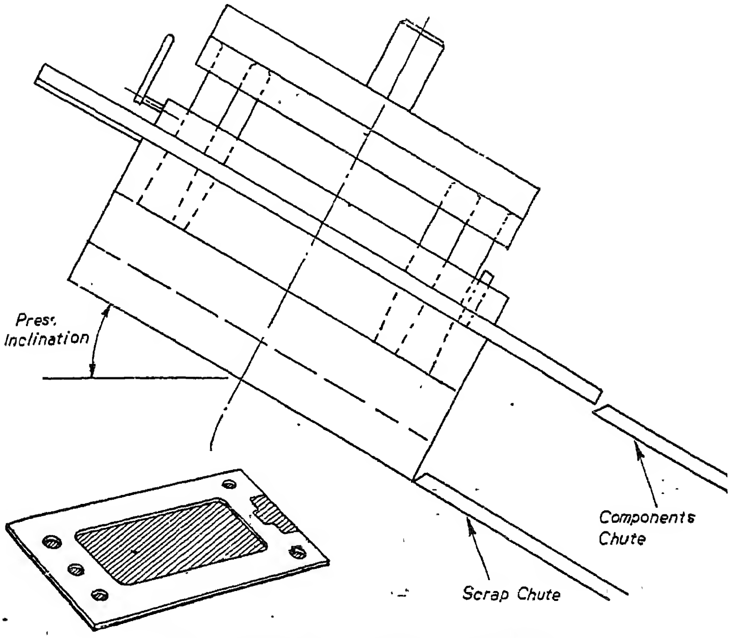


Fig. 40.—Cropping guillotined blank using inclined press.

simple upstroke press having a power of fifty tons or less. The action of the press depends upon the fact that the water or other operating fluid is almost incompressible, and also, that, having a very low internal resistance, any stress to which it is subjected is transmitted equally in all directions. Thus, if fluid under a pressure of p pounds per square inch is admitted to a cylinder which contains a movable plunger or ram of a diameter d inches, the pressure will be exerted upon the whole area of the ram $\left(\frac{\pi d^2}{4} \text{ square inches}\right)$ and the ram will exert a thrust of $\frac{\pi d^2 p}{4}$ pounds, provided that suitable means have been adopted to prevent leakage of the pressure fluid around the surface of the ram.

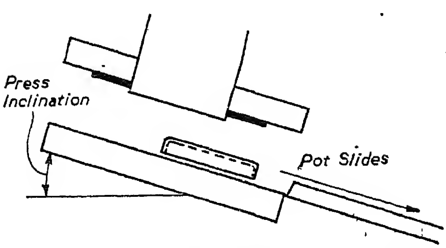


Fig. 41.—Use of high stripper tool and tilted press to eject a shallow pot.

Considering one of the simplest types of press, the upstroke type shown in Fig. 42, this consists of a cylinder A, standing upon a base cast upon the lower end, and having four lugs on the upper portion to carry the columns. The mouth of the cylinder is machined to form a guide for the ram B which slides within it, and upon which is mounted the moving head or crosshead C. The four columns serve to support the fixed top head D, and also act as guides for the cross-head. Shoulders formed on the columns maintain a fixed distance between the cylinder and the top head, and nuts on the outer ends of the columns bind the whole press together. Various forms of packings may be used in the cylinder mouth to prevent leakage, the one shown consisting of a U-shaped leather ring fitting in a groove in the cylinder. The pressure of the operating fluid forces the sides of the ring against the cylinder wall and ram respectively, forming an effective seal which has the advantage that the pressure exerted against the surface of the ram is proportional to the pressure of the fluid, thereby reducing friction to a minimum during the falling stroke, when the pressure is low. This is important in the press shown, as the falling stroke is due to the weight of the moving parts only, and this may not be great enough in a small press to overcome the friction of packings such as hemp which need squeezing tight to be effective. The leather is then allowed to spring out into the groove and the ram lowered.

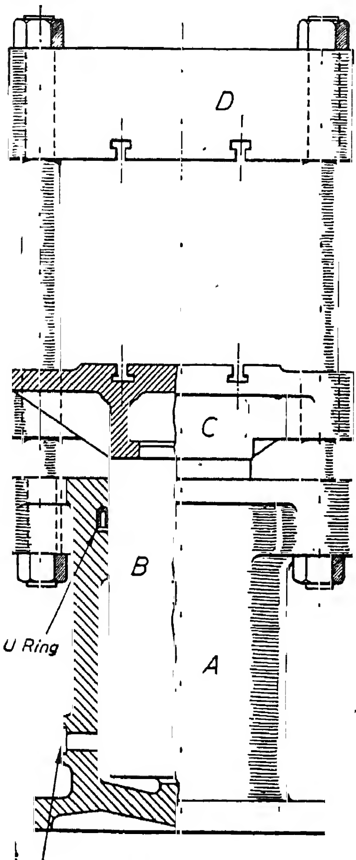


Fig. 42.—The upstroke type, which is one of the simplest forms of press.

For pressures up to, say, one ton per square inch, a cylinder of the type shown would be made of a high-grade cast iron, cast or forged steel being used for high pressure, the latter being designed as a loose cylinder seated in the base. For ordinary duty without much shock, the allowable stresses may be taken as up to 3000 pounds per square inch for cast iron, with 10,000 pounds per square inch for cast and forged steel respectively, and the thickness of the walls found from any of the well-known cylinder formulæ.

The pipe formula:

$$t = \frac{p \times d}{2f}$$

may be used as an approximation, where

t = Wall thickness, in inches.
p = Internal pressure in pounds per square inch.
d = Inside diameter of cylinder in inches.
f = Allowable stress in pounds per square inch,

but it must be remembered that this holds good only for thin-walled cylinders, and the allowable stress must be kept low if this formula is used.

NEWALL LIMITS

NOTE.—Where the larger sizes are concerned, say all those over 12 in. (300 mm.), it is necessary in each instance to consider carefully the materials, the quality of finish, and the length of engagement between shaft and hole, as these factors all affect the amount of tolerance necessary to secure the desired quality of fit. In the case of both FORCE and DRIVING fits, classes F and D, where limits and tolerances are not provided in these tables for sizes over 12 in. (300 mm.), the Newall Company is at all times ready to suggest suitable limits on receipt of detailed particulars of the work to be done.

Tolerances in Standard Holes

(Inches)	*Class A* High	*Class A* Low	*Class A* Tolerance	*Class B* High	*Class B* Low	*Class B* Tolerance
Up to and including ½	+ 0·00025	— 0·00025	0·0005	+ 0·0005	— 0·0005	0·001
Over ½ up to 1	+ 0·0005	— 0·00025	0·00075	+ 0·00075	— 0·0005	0·00125
,, 1 ,, 2	+ 0·00075	— 0·00025	0·001	+ 0·001	— 0·0005	0·0015
,, 2 ,, 3	+ 0·001	— 0·0005	0·0015	+ 0·00125	— 0·00075	0·002
,, 3 ,, 4	+ 0·001	— 0·0005	0·0015	+ 0·0015	— 0·00075	0·00225
,, 4 ,, 5	+ 0·001	— 0·0005	0·0015	+ 0·00175	— 0·00075	0·0025
,, 5 ,, 6	+ 0·0015	— 0·0005	0·002	+ 0·002	— 0·001	0·003
,, 6 ,, 7	+ 0·0015	— 0·00075	0·00225	+ 0·00225	— 0·001	0·00325
,, 7 ,, 8	+ 0·00175	— 0·001	0·0025	+ 0·00225	— 0·00125	0·0035
,, 8 ,, 9	+ 0·00175	— 0·001	0·00275	+ 0·0025	— 0·00125	0·00375
,, 9 ,, 10	+ 0·00175	— 0·001	0·00275	+ 0·0025	— 0·00125	0·00375
,, 10 ,, 11	+ 0·002	— 0·001	0·003	+ 0·00275	— 0·00125	0·004
,, 11 ,, 12	+ 0·002	— 0·001	0·003	+ 0·00275	— 0·0015	0·00425
,, 12 ,, 13	+ 0·002	— 0·001	0·003	+ 0·003	— 0·0015	0·0045
,, 13 ,, 14	+ 0·00225	— 0·001	0·00325	+ 0·003	— 0·0015	0·0045
,, 14 ,, 15	+ 0·00225	— 0·00125	0·0035	+ 0·003	— 0·00175	0·00475
,, 15 ,, 16	+ 0·0025	— 0·00125	0·00375	+ 0·00325	— 0·00175	0·005
,, 16 ,, 17	+ 0·0025	— 0·00125	0·00375	+ 0·00325	— 0·00175	0·005
,, 17 ,, 18	+ 0·0025	— 0·00125	0·00375	+ 0·00325	— 0·00175	0·005
,, 18 ,, 19	+ 0·0025	— 0·00125	0·00375	+ 0·0035	— 0·002	0·0055
,, 19 ,, 20	+ 0·00275	— 0·00125	0·004	+ 0·0035	— 0·002	0·0055
,, 20 ,, 21	+ 0·00275	— 0·00125	0·004	+ 0·00375	— 0·002	0·00575
,, 21 ,, 22	+ 0·00275	— 0·0015	0·00425	+ 0·00375	— 0·002	0·00575
,, 22 ,, 23	+ 0·003	— 0·0015	0·0045	+ 0·00375	— 0·002	0·00575
,, 23 ,, 24	+ 0·003	— 0·0015	0·0045	+ 0·004	— 0·002	0·006
,, 24 ,, 25	+ 0·003	— 0·0015	0·0045	+ 0·004	— 0·00225	0·00625
,, 25 ,, 26	+ 0·003	— 0·0015	0·0045	+ 0·004	— 0·00225	0·00625
,, 26 ,, 27	+ 0·00325	— 0·0015	0·00475	+ 0·00425	— 0·00225	0·0065
,, 27 ,, 28	+ 0·00325	— 0·0015	0·00475	+ 0·00425	— 0·00225	0·0065
,, 28 ,, 29	+ 0·0035	— 0·00175	0·00525	+ 0·00425	— 0·0025	0·00675
,, 29 ,, 30	+ 0·0035	— 0·00175	0·00525	+ 0·0045	— 0·0025	0·007

NEWALL LIMITS—*continued*

FORCE AND DRIVING FITS

(Inches)	*Allowances on Shafts for Force Fits*			*Allowances on Shafts for Driving Fits*		
	Class F			*Class D*		
	High	*Low*	*Tolerance*	*High*	*Low*	*Tolerance*
Up to and including ½	+ 0·001	+ 0·0005	0·0005	+ 0·0005	+ 0·00025	0·00025
Over ½ up to 1	+ 0·002	+ 0·0015	0·0005	+ 0·001	+ 0·00075	0·00025
,, 1 ,, 2	+ 0·004	+ 0·003	0·001	+ 0·0015	+ 0·001	0·0005
,, 2 ,, 3	+ 0·006	+ 0·0045	0·0015	+ 0·0025	+ 0·0015	0·001
,, 3 ,, 4	+ 0·008	+ 0·006	0·002	+ 0·003	+ 0·002	0·001
,, 4 ,, 5	+ 0·010	+ 0·008	0·002	+ 0·0035	+ 0·0025	0·001
,, 5 ,, 6	+ 0·012	+ 0·010	0·002	+ 0·004	+ 0·003	0·001
,, 6 ,, 7	+ 0·014	+ 0·012	0·002	+ 0·0045	+ 0·003	0·0015
,, 7 ,, 8	+ 0·016	+ 0·014	0·002	+ 0·005	+ 0·0035	0·0015
,, 8 ,, 9	+ 0·018	+ 0·016	0·002	+ 0·0055	+ 0·004	0·0015
,, 9 ,, 10	+ 0·020	+ 0·018	0·002	+ 0·006	+ 0·0045	0·0015
,, 10 ,, 11	+ 0·022	+ 0·020	0·002	+ 0·0065	+ 0·0045	0·002
,, 11 ,, 12	+ 0·024	+ 0·022	0·002	+ 0·007	+ 0·005	0·002

Note: The B.S.I. standards for first-quality, second-quality, third-quality, and extra-fine-quality work are sometimes specified.

NEWALL LIMITS—*continued*

Push and Running Fits

(Inches)	*Allowances on Shafts for Push Fits* — Class P			*Allowances on Shafts for Running Fits* — Class X		
	High	*Low*	*Tolerance*	*High*	*Low*	*Tolerance*
Up to and including ½	— 0·00025	— 0·00075	0·0005	— 0·001	— 0·002	0·001
Over ½ up to 1	— 0·00025	— 0·00075	0·0005	— 0·00125	— 0·00275	0·0015
„ 1 „ 2	— 0·00025	— 0·00075	0·0005	— 0·00175	— 0·0035	0·00175
„ 2 „ 3	— 0·0005	— 0·001	0·0005	— 0·002	— 0·00425	0·00225
„ 3 „ 4	— 0·0005	— 0·001	0·0005	— 0·0025	— 0·005	0·0025
„ 4 „ 5	— 0·0005	— 0·001	0·0005	— 0·003	— 0·00575	0·00275
„ 5 „ 6	— 0·0005	— 0·001	0·0005	— 0·0035	— 0·0065	0·003
„ 6 „ 7	— 0·0005	— 0·00125	0·00075	— 0·0035	— 0·00675	0·00325
„ 7 „ 8	— 0·0005	— 0·0015	0·001	— 0·0035	— 0·007	0·0035
„ 8 „ 9	— 0·0005	— 0·0015	0·001	— 0·00375	— 0·0075	0·00375
„ 9 „ 10	— 0·00075	— 0·002	0·00125	— 0·004	— 0·008	0·004
„ 10 „ 11	— 0·00075	— 0·002	0·00125	— 0·004	— 0·00825	0·00425
„ 11 „ 12	— 0·00075	— 0·002	0·00125	— 0·00425	— 0·0085	0·00425
„ 12 „ 13	— 0·00075	— 0·00225	0·0015	— 0·00475	— 0·009	0·00425
„ 13 „ 14	— 0·00075	— 0·00225	0·0015	— 0·00475	— 0·00925	0·0045
„ 14 „ 15	— 0·00075	— 0·00225	0·0015	— 0·005	— 0·0095	0·0045
„ 15 „ 16	— 0·001	— 0·0025	0·0015	— 0·00525	— 0·00975	0·0045
„ 16 „ 17	— 0·001	— 0·0025	0·0015	— 0·00525	— 0·010	0·00475
„ 17 „ 18	— 0·001	— 0·0025	0·0015	— 0·0055	— 0·0105	0·005
„ 18 „ 19	— 0·001	— 0·0025	0·0015	— 0·0055	— 0·01075	0·00525
„ 19 „ 20	— 0·001	— 0·00275	0·00175	— 0·00575	— 0·01125	0·0055
„ 20 „ 21	— 0·001	— 0·00275	0·00175	— 0·006	— 0·01150	0·0055
„ 21 „ 22	— 0·001	— 0·00275	0·00175	— 0·006	— 0·01175	0·00575
„ 22 „ 23	— 0·001	— 0·00275	0·00175	— 0·0065	— 0·01225	0·00575
„ 23 „ 24	— 0·00125	— 0·003	0·00175	— 0·0065	— 0·01225	0·00575
„ 24 „ 25	— 0·00125	— 0·003	0·00175	— 0·0065	— 0·01275	0·00625
„ 25 „ 26	— 0·00125	— 0·003	0·00175	— 0·0065	— 0·01275	0·00625
„ 26 „ 27	— 0·00125	— 0·00325	0·002	— 0·007	— 0·0135	0·0065
„ 27 „ 28	— 0·00125	— 0·00325	0·002	— 0·007	— 0·0135	0·0065
„ 28 „ 29	— 0·00125	— 0·00325	0·002	— 0·007	— 0·0135	0·0065
„ 29 „ 30	— 0·00125	— 0·00325	0·002	— 0·007	— 0·0135	0·0065

NEWALL LIMITS *continued*

Running Fits

Allowances on Shafts for Running Fits

(Inches)	Class Y High	Class Y Low	Class Y Tolerance	Class Z High	Class Z Low	Class Z Tolerance
Up to and including ½	− 0·00075	− 0·00125	0·0005	− 0·005	− 0·00075	0·00025
Over ½ up to 1	− 0·001	− 0·002	0·001	− 0·00075	− 0·000125	0·0005
,, 1 ,, 2	− 0·00125	− 0·0025	0·00125	− 0·00075	− 0·0015	0·00075
,, 2 ,, 3	− 0·0015	− 0·003	0·0015	− 0·001	− 0·002	0·001
,, 3 ,, 4	− 0·002	− 0·0035	0·0015	− 0·001	− 0·00225	0·00125
,, 4 ,, 5	− 0·00225	− 0·004	0·00175	− 0·00125	− 0·0025	0·00125
,, 5 ,, 6	− 0·0025	− 0·0045	0·002	− 0·00125	− 0·00275	0·0015
,, 6 ,, 7	− 0·00275	− 0·00475	0·002	− 0·00125	− 0·00275	0·0015
,, 7 ,, 8	− 0·00275	− 0·005	0·00225	− 0·0015	− 0·003	0·0015
,, 8 ,, 9	− 0·003	− 0·0055	0·0025	− 0·0015	− 0·003	0·0015
,, 9 ,, 10	− 0·00325	− 0·00575	0·0025	− 0·0015	− 0·00325	0·00175
,, 10 ,, 11	− 0·00325	− 0·006	0·00275	− 0·00175	− 0·0035	0·00175
,, 11 ,, 12	− 0·0035	− 0·00625	0·00275	− 0·00175	− 0·0035	0·00175
,, 12 ,, 13	− 0·00375	− 0·0065	0·00275	− 0·002	− 0·00375	0·00175
,, 13 ,, 14	− 0·00375	− 0·00675	0·003	− 0·002	− 0·00375	0·00175
,, 14 ,, 15	− 0·004	− 0·007	0·003	− 0·002	− 0·004	0·002
,, 15 ,, 16	− 0·0045	− 0·00775	0·00325	− 0·0025	− 0·0045	0·002
,, 16 ,, 17	− 0·0045	− 0·00775	0·00325	− 0·0025	− 0·0045	0·002
,, 17 ,, 18	− 0·0045	− 0·008	0·0035	− 0·0025	− 0·0045	0·002
,, 18 ,, 19	− 0·0045	− 0·008	0·0035	− 0·0025	− 0·0045	0·002
,, 19 ,, 20	− 0·005	− 0·0085	0·0035	− 0·00275	− 0·005	0·00225
,, 20 ,, 21	− 0·005	− 0·0085	0·0035	− 0·00275	− 0·005	0·00225
,, 21 ,, 22	− 0·005	− 0·00875	0·00375	− 0·0075	− 0·005	0·00225
,, 22 ,, 23	− 0·00525	− 0·009	0·00375	− 0·003	− 0·00525	0·00225
,, 23 ,, 24	− 0·00525	− 0·009	0·00375	− 0·003	− 0·00525	0·00225
,, 24 ,, 25	− 0·00525	− 0·00925	0·004	− 0·003	− 0·00525	0·00225
,, 25 ,, 26	− 0·00525	− 0·00925	0·004	− 0·003	− 0·00525	0·00225
,, 26 ,, 27	− 0·00575	− 0·00975	0·004	− 0·00325	− 0·00575	0·0025
,, 27 ,, 28	− 0·00575	− 0·00975	0·004	− 0·00325	− 0·00575	0·0025
,, 28 ,, 29	− 0·00575	− 0·010	0·00425	− 0·00325	− 0·00575	0·0025
,, 29 ,, 30	− 0·00575	− 0·010	0·00425	− 0·00325	− 0·00575	0·0025

SOFT AND HARD SOLDERING

Soft soldering is an alloying process, in which the tin in the solder combines with the metals of the joint, so that alloying is obtained; this takes place only if clean metal and clean solder are brought into contact. In normal practice the joint members are often dirty or rusty and may acquire a film of grease through handling; but even if the metal is perfectly clean beforehand, it will oxidise as soon as it is heated.

The colouring of copper or iron on heating is a simple example of the production of oxide films on a metal surface; but the oxide films are also formed during the gentle heating used in soft soldering, although they may be so thin as to be invisible. Nevertheless they form a barrier through which the solder cannot penetrate.

The removal of this oxide can be readily obtained by the use of a flux, which combines chemically with the oxide and floats it off the surface; the molten solder is thus able to spread over and tin the clean basis metal exposed. In addition, the flux shields the surfaces against further oxidation during the soldering operation.

These, then, are the two functions of a flux. First, to clean the surfaces to be joined, and secondly to protect them from oxidation.

Soldering Fluxes.—Soft-soldering fluxes can be divided into three main categories:

(1) Active or chloride fluxes.
(2) Electrical or resin-base fluxes.
(3) General safety fluxes.

Active Fluxes: These are chloride fluxes and are used for most soldering duties. They will remove quite considerable amounts of oxide, rust, or grease from the base metal. Killed spirit has been used in the past, but it is very corrosive and tends to leave a sticky residue in the joint itself. Certain commercial fluxes do not suffer from these disadvantages to the same extent, and are widely used on tinplate, terneplate, iron, steel, brass, copper, bronze, zinc, galvanised iron, nickel, etc. Flux of this nature is supplied in several forms—as a paste flux, as a tinning salt, and as a soldering fluid.

Special tinning salt is very widely used nowadays. It is a highly concentrated powder flux, which readily dissolves in cold or hot water, and should be used to the proportion of 2–4 lb. of salt per gallon of water. A stronger solution of 5½ lb. per gallon is equivalent to A.M. Specification D.T.D.81.

Electrical Fluxes: The safety fluxes are not so rapid in action as the chloride fluxes and are less effective in removing surface oxide; thus it is necessary that soldering should be done on reasonably clean surfaces. These resin-base fluxes form a protective film over the part, preventing oxidation at the soldering temperature. Such fluxes are available in four forms: (*a*) paste flux, (*b*) soldering fluid, (*c*) solder cream, (*d*) cored solder wire, and are mainly intended for use on electrical and radio assemblies, where complete freedom from acid or corrosive action is necessary.

Solder Paints, Creams, and Compounds: Reference should also be made to solder paints, solder creams, and tinning compounds, which are widely used nowadays for tinning and sweat soldering. They are mixtures of powdered solder (or pure tin) combined with flux. The creams and paints are applied with a brush to the joint members, and tinning or sweating is obtained by heating with a blowflame, a soldering-iron, on a hot-plate, or by passage through an oven. The flux residue, in the case of the solder paint, can easily be removed, if necessary, by a water wash. The tinning compound is very active and is used, for example, for the tinning of bearings shells.

Solder.—During recent years, solders with a much lower tin content have been more widely adopted, owing to the necessity for economising in the use of tin. In general, these lower-tin solders have proved in every way satisfactory, although it must be admitted that the pre-war tin-rich solders are quicker in operation and easier to use.

MELTING-POINTS AND STRENGTHS OF SOLDERS

	Melting-points Liquid	*Melting-points* Solidus	*Freezing Range*	*Specific Gravity*	*Tensile Strength, tons/sq. in.*	*Elongation, % on 2 in.*
Eutectic solder	183° C. 361° F.	183° C. 361° F.	— —	8·42	4·4	32
Grade A 65/35	186° C. 367° F.	183° C. 361° F.	3° C. 6° F.	8·35	4·9	20
Grade B 50/50	205° C. 401° F.	183° C. 361° F.	22° C. 40° F.	8·87	4·4	67
Grade C 40/60	230° C. 446° F.	183° C. 361° F.	47° C. 85° F.	9·33	4·1	63
Grade D plumber's	252° C. 486° F.	183° C. 361° F.	69° C. 125° F.	9·85	3·5	70
Grade F 50/50	210° C. 410° F.	183° C. 361° F.	27° C. 49° F.	8·83	3·8	69
Grade G 42/58	233° C. 451° F.	183° C. 361° F.	50° C. 90° F.	9·20	4·16	83
Grade K 60/40	184° C. 363° F.	183° C. 361° F.	1° C. 2° F.	8·46	4·0	52
Grade M 45/55	217° C. 423° F.	183° C. 361° F.	34° C. 62° F.	9·10	4·4	65
Grade N 18/82	278° C. 532° F.	183° C. 361° F.	95° C. 171° F.	10·45	3·5	22

Grade C (40 per cent. tin) is recommended for general hand soldering, while Grade M (45 per cent.) is a more fluid alloy for use on more difficult jobs. Grade G should be used for electrical work. The low tin-content solder, Grade N, is specified for hot dipping work.

In addition there are several tin-economy solders, such as Argent, T.M.5, and T.M.6. These solders have a wide field of application, and their use should always be explored in order to minimise the consumption of tin; but they cannot completely replace the normal tin-lead alloys.

Soft solders are normally available in the following forms:

Tinman's, ½-lb. or ¼-lb. sticks.
Ingots, nuggets, or blocks.
Thin blowpipe strips.
Solid solder wire.
Cored solder wire.
Solder tape and strip.
Solder washers.
Solder creams and paints.

Solid and Cored Solder Wire: Solders to all specifications are available in wire form.

Solid solder wire: All sizes down to 25 S.W.G.

Cored wire, Resin-cored wire, Acid-cored wire $\}$ All sizes down to 19 S.W.G.

For electrical and radio work resin-cored solder should be used. Alcho-re is to be preferred; it is very much quicker than resin, but just as safe to use.

Acid-cored is intended only for special duties and contains a strong chloride flux.

Soldering Zinc.—In any soldering operation the molten solder alloys with the base metal and often dissolves some of it. This action takes place rapidly

when soldering zinc ; this not only leads to contamination of zinc in the solder, which causes sluggishness in running, but also with normal solders leads to the formation of a hard, brittle compound. Successful soldering with a clean smooth finish can be obtained from Fry's No. 1 or No. 2 zinc solder.

Soldering Cast Iron.—Cast iron is somewhat difficult to solder owing to the presence of graphite and non-metallic inclusions. Pickling in hydrochloric acid before tinning is sometimes recommended, but this method is dangerous and not always successful. For many duties good tinning can be obtained, after grinding the surface, with solders to B.S.S. Grades C or M. For the tinning of cast-iron shells, it is advisable to use a tinning compound on account of its increased activity.

Soldering Aluminium.—A special technique is required for aluminium. The metal forms an oxide skin on the surface which is not removed by the ordinary soldering fluxes ; the oxide must be removed mechanically during the soldering operation. The aluminium solder is melted on the metal to exclude air whilst the surface beneath the molten solder is scraped or rubbed with a sharp tool such as a hacksaw blade or scratchbrush. With " Fryal," the amount of scraping is reduced or eliminated ; often good tinning can be obtained by rubbing the solder sticks on the heated aluminium. Once a tinned surface has been obtained with aluminium solder, the joint can be completed, if necessary, with ordinary tinsmith's solder. The soldering temperature is in the neighbourhood of 250° C.

Aluminium corrodes readily in moist conditions when in contact with other metals ; thus the use of aluminium solder is limited. It is suitable for dry joints, but it is advisable to protect the joint by a coat of varnish or lacquer. Aluminium solders are thus not suitable for kettles and saucepans—welding is the best method of repair.

Solders for Hot Dipping.—Hot tinning is normally employed to provide a protective coating. The following technique is recommended :

(1) Degreasing : If the article is greasy, treatment in an alkaline solution or in a trichlorethylene vat is necessary.

(2) Pickling : The surface must be free from oxide. Pickle solutions containing sulphuric, hydrochloric, or nitric acid are used, according to the metal being treated.

(3) Fluxing : After washing, the article is dipped in flux. An active flux of the " Frysol " type is used for all except special purposes.

(4) Dipping in molten solder : The time of immersion should be no longer than that required to bring the articles to the temperature of the solder bath and obtain a clean smooth coating. Usually only a few seconds.

Grade N solder is normally used. The best dipping temperature is about 400° C. Temperature control is important.

Soldering Stainless Steels.—The normal tin-lead solders are satisfactory, but Grade M is to be preferred. Most difficulties are due to use of the wrong type of flux. A non-corrosive flux of the phosphate type is frequently satisfactory.

Soldering Tinplate, Terneplate, Brass, and Copper.—Generally speaking, these metals are easily soldered. Successful results can be obtained with practically any grade of solder (B.S.S. Grades C, G, or M) and with an active or safety flux. Oleic acid No. 10 is the best safety non-corrosive flux for use on tinplate or terneplate. It is sometimes necessary to carry out preliminary degreasing before soldering, but this is very rare.

Soldering Electro-tinned Articles.—Difficulties are often experienced in this operation and are due to two main features :

(1) Insufficient thickness of electro-tin deposit. The minimum thickness should be 0·002 in.

(2) Time lag between electro-tinning and soldering. Soldering should normally be done immediately after or within two days of electro-plating.

Soldering should preferably be done with Grade M solder. Either an active or safety flux is suitable.

Solder Washers.—There is an increasing use of solder washers, blanks, discs, ribbon, and strip, which can be supplied to any given size, specification, or shape. The solder is fluxed before location, and jigging and soldering or sweating are obtained on a hot plate or by passing the assembly through a continuous furnace or oven, or by the electrode method.

Soft Solders for Elevated Temperatures.—The ordinary soft tin-lead solders commence to melt at 183° C. (361° F.), but as they approach this temperature their strength falls rapidly. The strength of a joint in brass made with ordinary tinman's solder is reduced by 75 per cent. when the temperature reaches 150° C. (302° F.). The loss in strength of soft solders is especially marked at temperatures above the boiling-point of water—100° C. (212° F.).

For soldered joints to withstand stresses at working temperatures of over 100° C., a special high-temperature solder should be used. As an example, ordinary solders often fail at the high temperatures encountered on armatures; this defect is remedied by soldering with a tin-base or lead-base alloy.

JOINT STRENGTH

Shear strength of joints (lap joints in brass)		*L.S.2*	*L.S.4*	*H.T.3*	*Grade B 50/50*
Tons per sq. in. at	18° C.	1·52	1·45	2·63	2·45
	100° C.	1·20	1·14	1·79	1·58
	150° C.	1·01	0·93	1·29	0·68
	200° C.	0·80	0·74	0·52	—

H.T.3 is a tin-rich alloy, free from lead. It is a free-flowing alloy and can be applied by the normal methods.

The Lead-base Solders: L.S.2 and L.S.4, which contain small amounts of silver and other constituents, will resist even higher temperatures than H.T.3. They are not quite so free flowing as the tin-base solder. With L.S.2 it is necessary to use an active flux to obtain good bonding; with L.S.4, which has better tinning properties, tinning can be obtained with a safety flux.

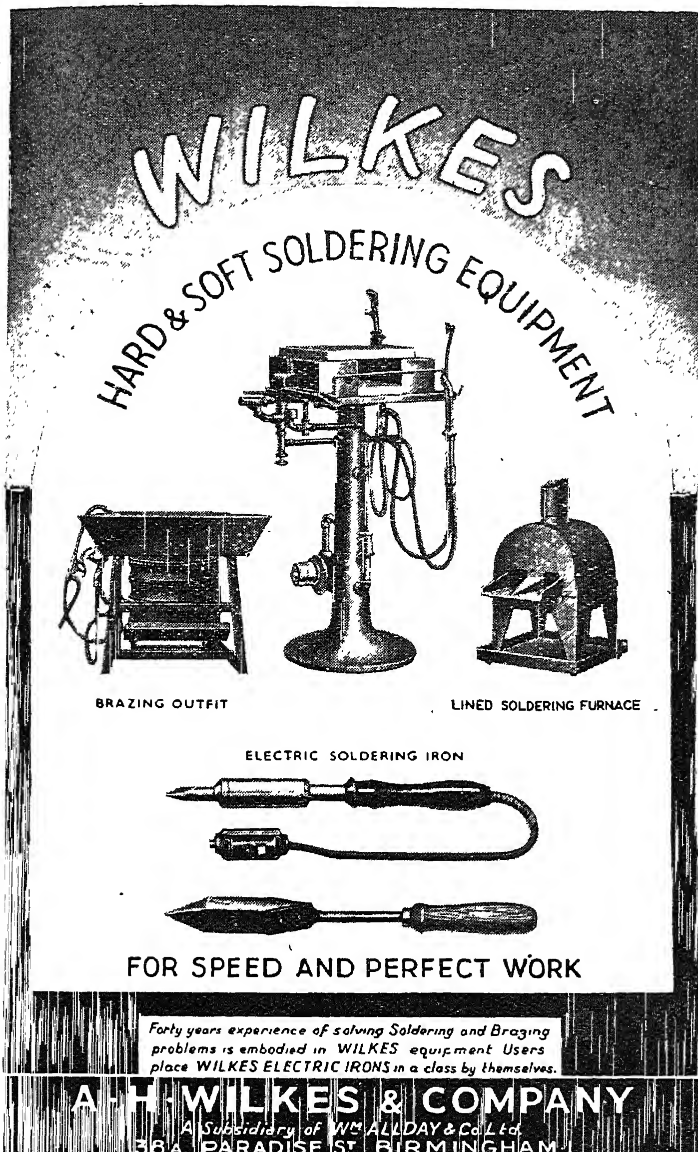
High-temperature solders are used for armatures, aircraft cooling systems, hot-water appliances, and electrical machinery.

Fusible Solders.—Alloys with very low melting-points are frequently used for special purposes. Among these may be mentioned solders for work which might be damaged by the temperature of application of tin-lead solders; in safety devices, e.g. for operating alarms or breaking the electrical circuit when the temperature exceeds the melting-point of the alloy; similarly, in fusible plugs for boilers; as fillers for the bending of thin-walled tubes; and setting media for the mounting of punches and dies.

Quality No.	*Alloy*	*Melting-points* ° C.	° F.
—	Tin-lead	183	361
18	Tin-lead-cadmium	142	288
17	Tin-bismuth	138	281
15	Lead-bismuth	124	255
9	Tin-lead-bismuth	93	203
2	Tin-lead-bismuth-cadmium	70	158

A special bending alloy, melting at 71° C., is used as a filler, providing the internal support necessary to prevent distortion in the bending of thin-walled tubes. The alloy is melted in hot water and poured into the tube, which is plugged at one end. The filling is then chilled rapidly by plunging the tube into cold water. After bending, the tube is emptied by melting out the alloy in hot water.

Matrix alloy is used for setting dies and punches in press tools. The die is placed in position by hand on its backing plate and the matrix alloy poured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round it. The alloy expands on solidification, and so holds the part firmly in position. The alloy can be poured at about 200° C., so that the temper of the die is not affected.

Hard Solders.—Hard solders were originally brasses containing a high proportion of zinc. More recently it has been found that the addition of silver to brass lowers the melting-point of the solder and gives a better joint. Silver solders are now employed extensively, despite their high cost.

Brazing Solders.—These usually contain about 50 per cent. of copper and 50 per cent. of zinc, and the melting-point is in the region of 870° C., i.e. at a red heat. With this alloy it is possible to braze the commonly used brasses which have melting-points of 900° C. or over, and, of course, higher melting-point metals, such as iron and steel.

The British Standards Specification No. 263, 1931, covers three grades of brazing solder :

	Copper	*Zinc*
Grade AA	59–61	Balance
Grade A	53–55	Balance
Grade B	49–51	Balance

Grade AA is intended for solder supplied in the form of wire or slittings.

With these solders, a borax-type flux is generally used.

Silver Solders.—These alloys are easier to apply than brazing solders ; they have superior fluidity, and give strong, sound joints. Three alloys are specified in British Standards Specification No. 206, 1941.

Grade	*Silver*	*Copper*	*Zinc*	*Cadmium*	*Melting-point, ° C.*
A . . .	61	29	10	—	690–735
B . . .	43	20	37	—	700–775
C (Fry's F.E.F.)	50	15	16	19	595–630

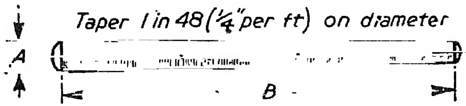
These solders can be used on copper, brass, bronze, steel, nickel, alloys, etc. Grade A has highest conductivity and is specified for electrical work.

Table of Decimal Equivalents

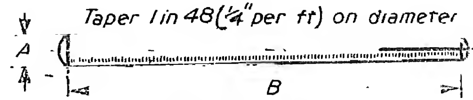
$\frac{1}{64}$ ..	0·015625	$\frac{17}{64}$ ..	0·265625	$\frac{33}{64}$ ..	0·515625	$\frac{49}{64}$ ..	0·765625
$\frac{1}{32}$ ..	0·03125	$\frac{9}{32}$ ..	0·28125	$\frac{17}{32}$ ..	0·53125	$\frac{25}{32}$ ..	0·78125
$\frac{3}{64}$ ..	0·046875	$\frac{19}{64}$ ..	0·296875	$\frac{35}{64}$ ..	0·546875	$\frac{51}{64}$ ..	0·796875
$\frac{1}{16}$ ..	0·0625	$\frac{5}{16}$ ..	0·3125	$\frac{9}{16}$ ..	0·5625	$\frac{13}{16}$ ..	0·8125
$\frac{5}{64}$ ..	0·078125	$\frac{21}{64}$ ..	0·328125	$\frac{37}{64}$ ..	0·578125	$\frac{53}{64}$ ..	0·828125
$\frac{3}{32}$ ..	0·09375	$\frac{11}{32}$ ..	0·34375	$\frac{19}{32}$ ..	0·59375	$\frac{27}{32}$ ..	0·84375
$\frac{7}{64}$ ..	0·109375	$\frac{23}{64}$ ..	0·359375	$\frac{39}{64}$ ..	0·609375	$\frac{55}{64}$ ..	0·859375
$\frac{1}{8}$ ..	0·1250	$\frac{3}{8}$ ..	0·375	$\frac{5}{8}$ ..	0·6250	$\frac{7}{8}$ ..	0·8750
$\frac{9}{64}$ ..	0·140625	$\frac{25}{64}$ ..	0·390625	$\frac{41}{64}$ ..	0·640625	$\frac{57}{64}$ ..	0·890625
$\frac{5}{32}$ ..	0·15625	$\frac{13}{32}$ ..	0·40625	$\frac{21}{32}$ ..	0·65625	$\frac{29}{32}$ ..	0·90625
$\frac{11}{64}$ ..	0·171875	$\frac{27}{64}$ ..	0·421875	$\frac{43}{64}$ ..	0·671875	$\frac{59}{64}$ ..	0·921875
$\frac{3}{16}$ ..	0·1875	$\frac{7}{16}$ ..	0·4375	$\frac{11}{16}$ ..	0·6875	$\frac{15}{16}$ ..	0·9375
$\frac{13}{64}$ ..	0·203125	$\frac{29}{64}$ ..	0·453125	$\frac{45}{64}$ ..	0·703125	$\frac{61}{64}$ ..	0·953125
$\frac{7}{32}$ ..	0·21875	$\frac{15}{32}$ ..	0·46875	$\frac{23}{32}$ ..	0·71875	$\frac{31}{32}$ ..	0·96875
$\frac{15}{64}$ ..	0·234375	$\frac{31}{64}$ ..	0·484375	$\frac{47}{64}$ ..	0·734375	$\frac{63}{64}$ ..	0·984375
$\frac{1}{4}$ ..	0·2500	$\frac{1}{2}$ ..	0·5000	$\frac{3}{4}$ ..	0·7500	1 ..	1·0000

TAPER PINS

B.S. 46, Part 3.



Solid Taper Pin



Split Taper Pin

Diameter at large end A ±0·002 in	Length B (in inches) ½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	4	4½	5	5½	6
in 1/16	○	○	○	○	○													
5/64	○	○	○	○	○													
3/32	○	⦶	⦶	○	○	○	○											
7/64	○	○	○	○	○	○	○											
1/8	○	⦶	⦶	⦶	⦶	⦶	⦶											
5/32	○	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶									
3/16		⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶				
7/32			⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶			
1/4			⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶		
9/32				○	○	○	○	○	○	○	○	○	○	○	○	○	○	
5/16				⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
11/32					○	○	○	○	○	○	○	○	○	○	○	○	○	○
3/8					⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
7/16							○	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
1/2									○	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶	⦶
9/16											○	○	○	⦶	⦶	⦶	⦶	⦶
5/8													○	⦶	⦶	⦶	⦶	⦶

All sizes shown ○ and ⦶ are standard for solid taper pins. Only those shown ⦶ are standard for split taper pins. The latter are split at the small end for not less than 20% of the length of the pin.

Taper per Foot (in.)	*Included*			*With Centre Line*			*Taper per Inch*	*Taper per Inch from Centre Line*
	Deg.	*Min.*	*Sec.*	*Deg.*	*Min.*	*Sec.*		
1/8	0	35	48	0	17	54	0·010416	0·005203
3/16	0	53	44	0	26	52	0·015625	0·007812
1/4	1	11	36	0	35	48	0·020833	0·010416
5/16	1	29	30	0	44	45	0·026042	0·013021
3/8	1	47	24	0	53	42	0·031250	0·015625
7/16	2	5	18	1	2	39	0·036458	0·018229
1/2	2	23	10	1	11	35	0·041667	0·020833
9/16	2	41	4	1	20	32	0·046875	0·023438
5/8	2	59	42	1	29	51	0·052084	0·026042
11/16	3	16	54	1	38	27	0·057292	0·028646
3/4	3	34	44	1	47	22	0·062500	0·031250
13/16	3	52	38	1	56	19	0·067708	0·033854
7/8	4	10	32	2	5	16	0·072917	0·036456
15/16	4	28	24	2	14	12	0·078125	0·039063
1	4	46	18	2	23	9	0·083330	0·041667
1¼	5	57	48	2	58	54	0·104666	0·052084
1½	7	9	10	3	34	35	0·125000	0·062500
1¾	8	20	26	4	10	13	0·145833	0·072917
2	9	31	36	4	45	48	0·166666	0·083332
2½	11	53	36	5	56	48	0·208333	0·104166
3	14	15	0	7	7	30	0·250000	0·125000
3½	16	35	40	8	17	50	0·291666	0·145833
4	18	55	28	9	27	44	0·333333	0·166666
4½	21	14	20	10	37	10	0·375000	0·187500
5	23	32	12	11	46	6	0·416666	0·208333
6	28	4	20	14	2	10	0·500000	0·250000

When the taper in inches per foot is known, to find the angle of taper, divide the taper in inches per foot by 24. The answer is the tangent of half the included angle.

STANDARD TAPERS

The tapers in general use are:

Morse: 0·625 in. per ft. (approx. for most sizes).

Actual Morse tapers are: No. 0 = 0·6246 in. per ft.; No. 1 = 0·5986; No. 2 = 0·5994; No. 3 = 0·6023; No. 4 = 0·6233; No. 5 = 0·6315; No. 6 = 0·6256; No. 7 = 0·6240.

Brown & Sharpe: 0·5 in. per ft. approx. (all sizes except H10 where the taper is 0·5161 in. per ft.).

Jarno: 0·6 in. per ft. on diameter (all sizes).

The Sellers taper, key-wayed throughout its length, is 0·75 in. per ft. It is without tang.

The Reed taper is 1 in 20, similar to the Jarno. It is chiefly used on lathes, but is different from the Jarno in the diameters and lengths.

The Standard Tool Company has initiated two tapers—short and standard. These tapers extend from 0·6 in. to 0·63 in. per ft.

In dealing with tapers the following abbreviations apply :

T.P.I. = taper per inch.
T.P.F. = taper per foot.
T.P.L. = taper per length.
D = large diameter.
d = smaller diameter.
l = length of the taper.

The following formulæ are used :

$$\text{T.P.I.} = \frac{\text{T.P.F.}}{12}$$

$$\text{T.P.F.} = \frac{12\,(D - d)}{l}$$

$$\text{T.P.L.} = \frac{l(\text{T.P.F.})}{12}$$

$$D = d + \left(\frac{l \times \text{T.P.F.}}{12}\right).$$

$$d = D - \left(\frac{l \times \text{T.P.F.}}{12}\right).$$

$$l = \frac{12\,(D - d)}{\text{T.P.F.}}.$$

WEIGHT OF STEEL BARS

(In ordinary lengths of 10 ft.)

Size	*Square*	*Round*	*Octagon*	*Hexagon*
In.	*Lb.*	*Lb.*	*Lb.*	*Lb.*
$\frac{1}{4}$	2·13	1·67	1·8	1·9
$\frac{5}{16}$	3·32	2·61	2·8	2·9
$\frac{3}{8}$	4·78	3·76	4·1	4·2
$\frac{7}{16}$	6·51	5·11	4·5	5·7
$\frac{1}{2}$	8·49	6·68	7·2	7·5
$\frac{9}{16}$	10·76	8·45	9·1	9·4
$\frac{5}{8}$	13·28	10·43	11·2	11·7
$\frac{11}{16}$	16·07	12·62	13·6	14·1
$\frac{3}{4}$	19·12	15·02	16·2	16·8
$\frac{13}{16}$	22·45	17·63	19·0	19·7
$\frac{7}{8}$	26·03	20·44	22·0	22·9
$\frac{15}{16}$	29·88	23·47	25·3	26·2
1	34·00	26·70	28·7	29·9
$1\frac{1}{16}$	38·50	30·30	32·5	33·7
$1\frac{1}{8}$	43·03	33·80	36·4	37·8
$1\frac{3}{16}$	48·10	37·90	40·6	42·1
$1\frac{1}{4}$	53·12	41·72	45·0	46·6
$1\frac{5}{16}$	58·80	46·30	49·6	51·4
$1\frac{3}{8}$	64·28	50·49	54·5	56·5
$1\frac{7}{16}$	70·50	55·50	59·5	61·7
$1\frac{1}{2}$	77·50	60·08	64·8	67·2
$1\frac{9}{16}$	83·30	65·60	70·3	72·9
$1\frac{5}{8}$	89·78	70·51	76·1	78·9
$1\frac{11}{16}$	97·20	76·50	82·0	85·0
$1\frac{3}{4}$	104·12	81·78	88·2	91·4
$1\frac{13}{16}$	112·10	88·30	94·6	98·1
$1\frac{7}{8}$	119·53	93·88	101·2	105·0
$1\frac{15}{16}$	128·10	100·90	108·1	112·1
2	136·00	106·81	115·2	119·5
$2\frac{1}{8}$	154·10	121·40	130·0	134·9
$2\frac{1}{4}$	172·80	136·10	145·8	151·2
$2\frac{3}{8}$	192·50	151·60	162·4	168·5
$2\frac{1}{2}$	213·30	168·00	180·0	186·6
$2\frac{5}{8}$	235·20	185·22	198·4	205·8
$2\frac{3}{4}$	258·10	203·30	217·8	225·9
$2\frac{7}{8}$	282·10	222·20	238·0	246·9
3	307·20	241·90	259·2	268·8

WOOD-SCREW PROPORTIONS

Standard Wood Screws

No. of Screw Gauge	Diameter in.	Diameter of Neck in.	Overall Diameter of Head in.	Depth of Head in.	Slot	
					Width in.	Depth in.
0	0·05784	1/16	7/64	1/32	1/64	1/64
1	0·07100	5/64	9/64	3/64	1/64	1/32
2	0·08416	5/64	11/64	3/64	1/64	1/32
3	0·09732	3/32	3/16	3/64	1/64	1/32
4	0·11048	7/64	7/32	1/16	1/32	1/32
5	0·12364	1/8	15/64	1/16	1/32	1/32
6	0·13680	9/64	17/64	5/64	1/32	3/64
7	0·14996	5/32	19/64	5/64	1/32	3/64
8	0·16312	5/32	21/64	3/32	3/64	3/64
9	0·17628	11/64	23/64	3/32	3/64	3/64
10	0·18944	3/16	3/8	7/64	3/64	1/16
11	0·20260	13/64	13/32	7/64	3/64	1/16
12	0·21576	7/32	7/16	1/8	3/64	1/16
13	0·22892	15/64	29/64	1/8	1/16	1/16
14	0·24208	1/4	31/64	9/64	1/16	1/16
15	0·25524	1/4	33/64	9/64	1/16	1/16
16	0·26840	17/64	17/32	5/32	1/16	5/64
17	0·28156	9/32	9/16	5/32	1/16	5/64
18	0·29472	19/64	19/32	11/64	5/64	5/64
19	0·30788	5/16	39/64	11/64	5/64	5/64
20	0·32104	21/64	41/64	11/64	5/64	5/64
21	0·33420	21/64	43/64	3/16	5/64	3/32
22	0·34736	11/32	11/16	3/16	3/32	3/32
23	0·36052	23/64	23/32	13/64	3/32	3/32
24	0·37368	3/8	3/4	13/64	3/32	3/32

FLOORING BRADS

Size	*Gauge*	*Approx. No. to Lb.*	*Size*	*Gauge*	*Approx. No. to Lb.*
20d	6	31	9d	10	90
16d	7	43	8d	10	100
12d	8	55	7d	11	140
10d	9	70	6d	11	156

TWIST DRILLS FOR WOOD SCREWS

No. (or Size) of Screw	*Diameter of Neck or Shank*		*For Wood or Metal*		*With Side Lips and Centre for Wood only*	
			No., etc.	*Diameter*	*Size*	*Diameter*
1	0·066	Stubb's Wire Gauge Drills	51	0·067	—	—
2	0·080		46	0·081	—	—
3	0·094		41	0·096	—	—
4	0·108		35	0·110	—	—
5	0·122		30	0·128	1/8	0·125
6	0·136		28	0·140	—	—
7	0·150		23	0·154	5/32	0·156
8	0·164		18	0·169	—	—
9	0·178		14	0·182	3/16	0·187
10	0·192		9	0·196	—	—
11	0·206		4	0·209	7/32	0·218
12	0·220		1	0·228	—	—
13	0·234	Letter Gauge Drills	B	0·238	—	—
14	0·248		E	0·250	1/4	0·250
15	0·262		H	0·266	—	—
16	0·276		K	0·281	9/32	0·281
17	0·290		M	0·295	—	—
18	0·304		O	0·316	5/16	0·312
19	0·318		P	0·323	—	—
20	0·332		R	0·339	11/32	0·343
21	0·346		S T	0·348 0·358	—	—
22	0·360		U	0·368	3/8	0·375
23	0·374		V	0·377	3/8	0·375
24	0·388		X	0·397	—	—
25	0·402		Z	0·413	13/32	0·406
26	0·416		27/64	0·421	—	—
27	0·430		7/16	0·437	7/16	0·437
28	0·444		29/64	0·453	—	—
29	0·458		15/32	0·468	15/32	0·468
30	0·472		31/64	0·484	—	—
31	0·486		1/2	0·500	1/2	0·500
32	0·500		31/64	0·515	1/2	0·500

All dimensions in parts of an inch.

PANEL PINS

Size	Gauge No.	Approx. No. to Lb.	Size	Gauge No.	Approx. No. to Lb.
20d	10	62	7d	13	236
16d	11	90	6d	13·5	310
12d	11·5	114	5d	15	500
10d	11·5	122	4d	15	586
9d	12·5	172	3d	15·5	606
8d	12·5	190	2d	16·5	1,350

BARBED BOX NAILS

Size	Gauge	Approx. No. to Lb.	Size	Gauge	Approx. No. to Lb.
40d	8	35	8d	11·5	146
30d	9	45	7d	12·5	210
20d	9	52	6d	12·5	234
16d	10	72	5d	14	404
12d	10·5	86	4d	14	474
10d	10·5	94	3d	14·5	636
9d	11·5	132	2d	15·5	1,008

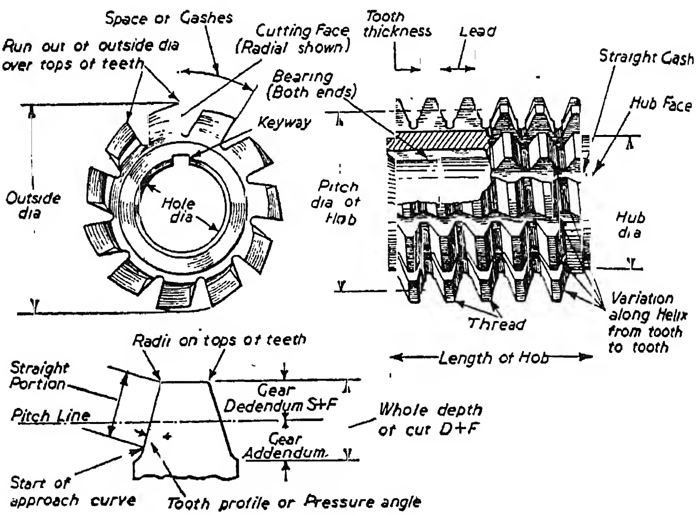
FENCING NAILS

Size	Gauge	Approx. No. to Lb.	Size	Gauge	Approx. No. to Lb.
20d	4	23	8d	9	81
16d	5	30	7d	9	92
12d	6	41	6d	10	125
10d	7	50	5d	10	142
9d	8	61			

WIRE NAILS AND BRADS

Size	*Gauge*	*Approx. No. to Lb.*	*Size*	*Gauge*	*Approx. No. to Lb.*
60d	2	11	9d	10·25	95
50d	3	16	8d	10·25	107
40d	4	18	7d	11·5	162
30d	5	24	6d	11·5	182
20d	6	31	5d	12·5	272
16d	8	50	4d	12·5	314
12d	9	64	3d	14	570
10d	9	70	2d	15	875

HOB TERMS AND PROPORTIONS



Let p_n = Normal pitch of tooth to be produced.
t = Number of threads in hob.
d = Pitch diameter of hob.
j = Outside diameter of hob.
λ = Lead angle of hob thread.
σ = Spiral angle of flutes.
F = Number of flutes.
L = Lead of threads.
l = Lead of flutes.

For hob made with solid shank:
Minimum desirable value of $d = 4p_n$.
For hob bored to mount on arbor:
Minimum desirable value of $d = 4p_n$ + diameter of arbor.
Outside diameter of hob j
$= d + 2 \times$ dedendum of gear tooth.

Lead of hob thread $L = tp_n + \dfrac{tp_n}{2\left(\dfrac{\pi d}{tp_n}\right)^2 - 1\cdot5}$ (if $\dfrac{\pi d}{tp_n}$ exceeds 4),

or $tp_n \Big/ \sqrt{1 - \left(\dfrac{tp_n}{\pi d}\right)^2}$ (in general); $\tan\lambda = \dfrac{L}{\pi d}$.

Tip radius of flute-cutter $= 0\cdot125p_n$.

Lead of flutes $l = \dfrac{\pi^2 d^2}{L}$.

Spiral angle of flutes $\sigma = \lambda$.

Number of flutes $F = \dfrac{\sqrt{[\pi^2 d^2 + L^2]}}{1\cdot3p_n}$ (taken to nearest whole number).

The number of flutes F and the number of threads t should preferably have no common factor.

Rise of relieving cam $= \dfrac{\sqrt{[\pi^2 j^2 + L^2]}}{10F}$ (approx.).

Ratio of change-gears for relieving cam:

$$\frac{\text{Product of numbers of teeth in driving gears}}{\text{Product of numbers of teeth in driven gears}}$$

$$= K \times \left(\frac{\text{Number of flutes}}{\text{Number of lobes in cam}}\right)\frac{l + L}{l}$$ where K is a constant for the machine.

The number of lobes in the cam is usually unity.

The hobbing process is the one that produces the most accurate cut gears, and it does demand a high standard of accuracy in the hob itself. To meet modern requirements the hob teeth must be finished by grinding on a machine in which the abrasive wheel head has a relieving motion whilst the hob is rotated and moved endwise.

The material used for hobs of normal dimensions is high-speed tool steel, containing about 0·75 per cent. carbon, 18 per cent. tungsten, 4 per cent. chromium, and 1·3 per cent. vanadium. This needs special care in forging to avoid the formation of cracks and, after turning and boring, careful inspection is required to detect any defect of this nature.

A boss about a quarter-inch wide is turned at each end of the hob in order to provide cylindrical surfaces for checking the true running of the hob in service. The keyway or driving slot is cut at this stage.

The thread (or threads) are then produced in a thread-milling machine. If quantities are involved it is often desirable to make a milling cutter specially formed to produce the required thread sections; otherwise the most closely approximating available cutter is used to rough out the thread, which is afterwards modified to the required shape by use of a form tool in the lathe.

The thread shape is checked by comparison with a gauge, or if it is straight-sided by the use of a sensitive tracer and dial indicator traversed in a straight line along a slide at the appropriate angle.

The flutes are produced on a milling machine using a cutter of 30° V-section, one side of which is perpendicular to the axis of the cutter. The vertical line through the plane containing these perpendicular edges is set to intersect the centre line of the hob flank, so that the cutting faee of each flute contains radial straight lines. The radius at the tip of the cutter is equal to about one-eighth of the normal pitch of the hob.

The angular setting of the table of the milling machine is the spiral angle of the flute at the pitch cylinder of the hob.

The relieving of the teeth is carried out on a relieving lathe. The tool is formed to match the thread form of the hob, a witness of 0·02 in. wide being left on each tooth.

RIVETS AND RIVETING

A rivet should be of good form (both types—commercial head and formed head); it should also securely clamp the joint without distortion, without cracks or scores in either head, have perfect alignment and good seating. One of the governing factors of the ideal rivet is the amount of rivet protruding through the joint. This amount varies with the type of rivet. Solid snap-head rivets should protrude approximately $1\frac{1}{2}$D, where D equals the diameter of the rivet. Countersunk rivets are $\frac{3}{4}$D, and tubular rivets $\frac{1}{2}$D. This applies to power-squeeze riveting; for hand and percussion operation, however, the rule is not hard-and-fast. The second rule is to use the correct drill; this in most cases is slightly larger than the diameter of the rivet.

Rivet Size	*Clear Drill*	*Dec. Equiv.*
in.		*in.*
$\frac{1}{8}$	No. 30	0·1285
$\frac{5}{32}$	No. 20	0·161
$\frac{3}{16}$	No. 10	0·1935
$\frac{1}{4}$	Letter F Drill	0·257

Material	*Clear*
	in.
Mild steel	0·003
Light alloy	0·006 0·009
Stainless steel	0·001

The tables above give the correct drill size for commonly used rivets. This clearance is to allow for the slight expansion which takes place in the shank of the rivet during the riveting process, and it is also regulated by the type of metal or material used. As a rough rule, the softer the material the greater the clearance. The table also gives clearances for metals in common use. When using tubular rivets no clearance is allowed; in fact, the holes should be reamed for a push fit.

Mild-steel rivets are usually cadmium coated, and are, of course, magnetic. Stainless steel and copper rivets are also used. Duralumin rivets are generally left their natural colour and carry an indentation on the head, usually "D." Aluminium rivets are stamped and sometimes coloured. This colouring depends on the existing colour scheme. Purple and green are the predominant colours in aircraft work—purple being NA16ST and green MG5. Neither of these rivets requires heat treatment before use. On the other hand, duralumin must be heat treated before use. The procedure is to heat treat the rivets to 490° C. for 20 minutes and then quench in water at 15° C. They can then be used for a period of between one and two hours. After heat treatment they can be kept workable for 48 hours by keeping them at a temperature below freezing-point. After removal from the refrigerator, the above time limit still applies.

Types and Shapes of Rivets.—The types and shapes of rivets in common use in aircraft and light engineering are snap-heads; these are supplied in a variety of shapes. Fig. 1 shows a few of these. Shovel rivets are probably the most commonly used. Other types are the "pop" rivet, the "chobert," and the "bifurcated" semitubular rivet; all these, too, are in common use.

To the above rivets may be added the cup and explosive types.

The Uses of Rivets.—Pop rivets are designed to overcome the difficulty of blind riveting. A pop rivet makes possible the application of riveting in otherwise inaccessible places. The pop rivet of nickel alloy is also as strong as an aluminium solid rivet.

Setting or clinching of these rivets is accomplished by means of a special tool. Pop rivets are supplied by the makers complete with a mandrel, similar in shape to a nail. These mandrels are made of hard steel and are made in three types—

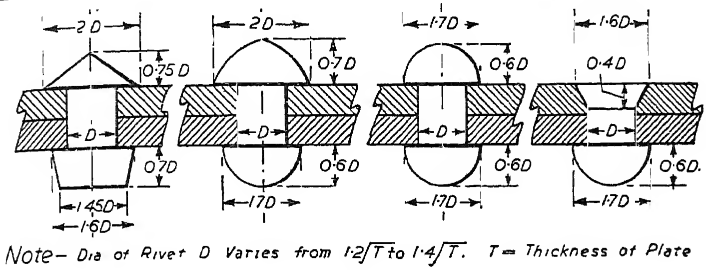


Fig. 1.—Rivet proportions.

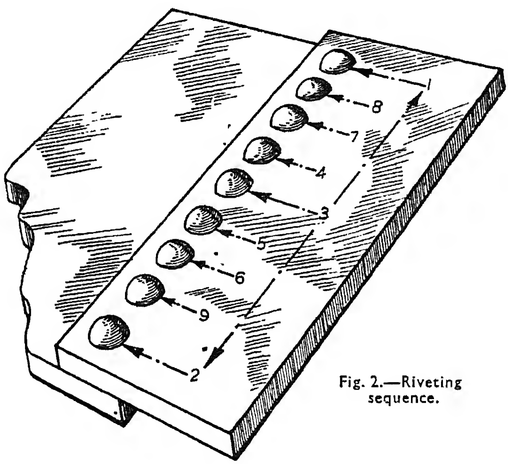


Fig. 2.—Riveting sequence.

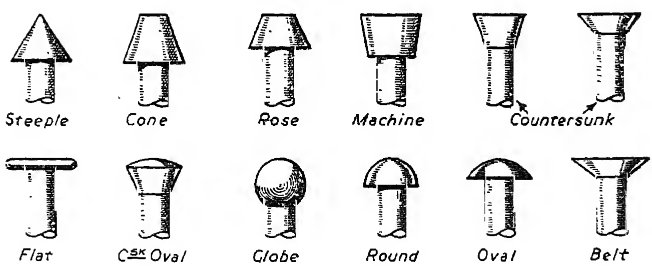


Fig. 3.—Types of rivet.

break head, break stem, and pull through. After the rivet is inserted in the hole of the joint, the mandrel is withdrawn by means of the setting tool; the mandrel or nail head, after upsetting or expanding the rivet shank, breaks off at the designed load, thus making a tight joint. The foregoing applies to the break-head and break-stem type. The procedure of pull-through riveting is similar, but in this case the head has a slight taper, a little larger than the rivet bore. After the rivet has been expanded by the withdrawal of the mandrel, the pressure exerted causes the taper head to deform to a smaller diameter, and thus allows it to pass through the bore of the rivet, leaving a tight joint. Another advantage of both pop and chobert riveting is that only one operator is needed. The expansion of the shank is between 0·060 in. and 0·080 in.

Chobert riveting is of a similar nature, but whereas in pop riveting the head or stem of the mandrel breaks, the chobert mandrel pulls through after expanding the shank of the rivet. In pop riveting the mandrel carries one rivet, in chobert the mandrel may carry as many as ninety. The estimated time to load and place an average chobert rivet is 3 seconds. Both the above-mentioned methods are of the mechanical type.

Bifurcated Semi-tubular Rivet.—This can be set by either hand or machine. The hand method is to place the rivet in its hole, hold on its head a dolly block, then draw it up with an ordinary drawing-up tool (on soft metals this should be made of fibre).

The next operation is usually to use the dimple snap, but it is best first to give the tubular shank a smart tap with a 60-degree punch. The hammer on this type of riveting should not be much over 4 oz. in weight.

In Fig. 3 are shown various types of standard rivets and their proportions. Fig. 4 shows riveting methods.

Riveting Methods.—The production of aircraft wings, tailplane assemblies, tanks and fuselage, and other parts in large quantities from aluminium-alloy sheets, has focused attention in the aircraft industry on improved methods of riveting, with a view to both speeding up production and ensuring accurate alignment of the parts. Large parts, such as wings, are often built up into sub-assemblies before being transferred to the main assembly jig.

The Jig Chain.—The normal type of assembly jig is a rigid framework provided with a number of specially designed clamps. An alternative arrangement which is finding increasing use, however, is the jig chain, which is primarily designed as a flexible drilling jig for use on simple curved and flat surfaces, but which can also be used as a clamp. An illustration of a typical fixture shows the manner in which the chain is attached at one end to an anchor plate and is tensioned at the other end by a drawbolt and block.

The chain itself consists of accurately pitched links fitted with case-hardened steel rollers. Each roller is grooved, so that two adjacent rollers form an accurate guide for the drill. An identification block at one end of the chain indicates the drill size and the pitch of the hole. Wear on the rollers is reduced to the minimum, due to the fact that they are free to revolve on the chain bushes and automatically take up a new position at each work setting. When using the chain as a drilling jig the spacing of the holes in the work may be equal to the pitch of the chain or a multiple of it. The chain pitches available are 0·375 in., 0·5 in., 0·625 in., 0·75 in., and 1 in., while various drill sizes, from 0·098 in. up to 0·257 in., are available.

When drilling large numbers of holes arranged in a pattern across a wing or other part, steel drilling plates having hardened bushes are, of course, most frequently used. An alternative to the steel plate which considerably reduces tooling time and cost, however, is a metal-faced plywood plate, used in conjunction with a Desoutter telescopic drill. The holes in the drilling plate are countersunk to take a spring-loaded conical guard which surrounds the nose of the drill. This guard accurately centres the drill in the hole, but does not allow it to touch the drilling plate. The same arrangement can be used on unbushed steel drilling plates having countersunk holes.

Work Clamps.—Assuming that the rivet holes have been accurately spaced, the main problem which now arises is to position the various sheets and hold them securely to the spars during riveting. With the object of simplifying assembly a number of ingenious riveting clamps have been developed.

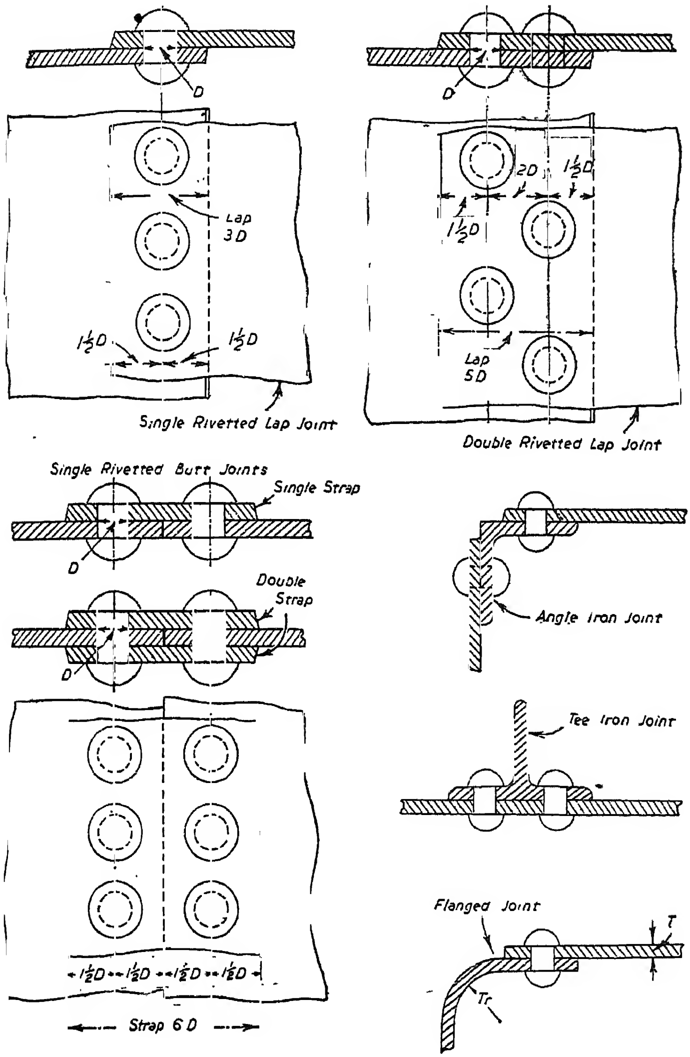


Fig. 4.—Riveting methods.

One of the simplest and at the same time most effective clamps is that patented by General Aircraft, Ltd., which is used not only when assembling their own aircraft, but is supplied to a number of other well-known manufacturers. The clamp consists of an "L"-shaped strip of polished spring steel, to which a steel rod is pivoted so that it swings in a slot in the strip. At its lower end the rod is bent through an angle of 90 degrees to form a hook.

In use, the clamp is hooked through the appropriate rivet holes so that the bent portion bears on the underside of the framework; the shoe at the base of the clamp is then slid over the skin so that the rod travels to the end of the slot, exerting a spring pressure on the skin.

The features of this clamp are the rapidity with which it can be fitted, the absence of any loose parts, and the comparatively broad base of the clamp which distributes the pressure and eliminates scratching or marking of the surface. The clamp can be employed on plates ranging in thickness from a minimum of about 2 × 26 G. to a maximum of 2 × 18 G., but it is important to employ a clamp which corresponds to the size of rivet used. At the moment two sizes are made: No. 1, which is suitable for $\frac{3}{32}$-in. rivets, and No. 2, for $\frac{1}{8}$-in. rivets.

Myers Clamp.—Another widely used type of clamp is the Myers design, which acts as an accurate plug gauge to register the two holes, and at the same time provides a positive clamping action through screw operation. It will be seen that an elongated flange of nearly the same diameter as the rivet hole is machined on the movable shank of the clamp. A second projection on the clamp combines with the reduced diameter of the stem to form a plug of the same diameter as the rivet hole, ensuring accurate location of the parts.

It will be seen that on spinning back the lock-nut and passing the shank through the hole, the clamp must be moved slightly upward before the second projection can enter the hole. The shank is then pulled back so that its flange grips the underside of the spar or second sheet of metal, when the lock-nut can be spun down and tightened to grip the surfaces securely.

Spencer Clamp.—Yet another type of clip is the Spencer clamp, in which the grip is actually applied inside the two holes, thus accurately locating the assembly and eliminating all risk of damage to either surface. The clamp is placed in position and locked with the aid of a special pair of pliers, fitting and removing it being practically instantaneous. It is claimed that since pliers must necessarily be used, the risk of cramp is eliminated and the possibility of septicæmia is reduced.

Automatic Riveting Machines.—A further aspect of the demand for speeding up riveting is the use of automatic punching and riveting machines. The riveting and piercing machine is of the hand-operated rack-and-pinion type, and can deal with duralumin rivets up to $\frac{5}{32}$ in. in diameter and aluminium rivets up to $\frac{3}{16}$ in.

A further machine is a spin riveter, which is employed to obviate buckling of long rivets, a fault which sometimes occurs when a rivet is not fully supported throughout its length, as when passing through a tube. Two small hardened wheels, free to rotate on a horizontal axis, have rims shaped to produce the desired head on the rivet. These wheels are carried on a vertical rotating shaft, which supplies the necessary pressure, but the peining action imparted by the wheels enables a lower pressure to be employed, preventing buckling. The holding-up dolly is provided with a deep hollow in the centre in order to impart a frictional grip to the edges of the rivet, thus preventing rotation.

Pneumatic Operation.—Riveting machines produced by specialist firms are usually of the hopper-fed type, and may be combined with a punch mechanism to form the holes prior to riveting. A range of machines, of the pedestal, beam, or semi-portable type, is manufactured by the Engineering and Research Corporation. These will punch holes up to $\frac{5}{32}$-in. diameter through layers of sheets having a combined maximum thickness of $\frac{5}{32}$ in., provided that the material does not exceed 30 tons per square inch tensile strength. The machines all work on the same principle, being operated pneumatically.

The punch is mounted in the lower frame member, working inside a stripper. In line with it a piston-rod projects downwards from the operating cylinder in the upper frame member, while behind the piston-rod is a vertical pin around which an arm carrying the punch, die, and rivet shoe swings.

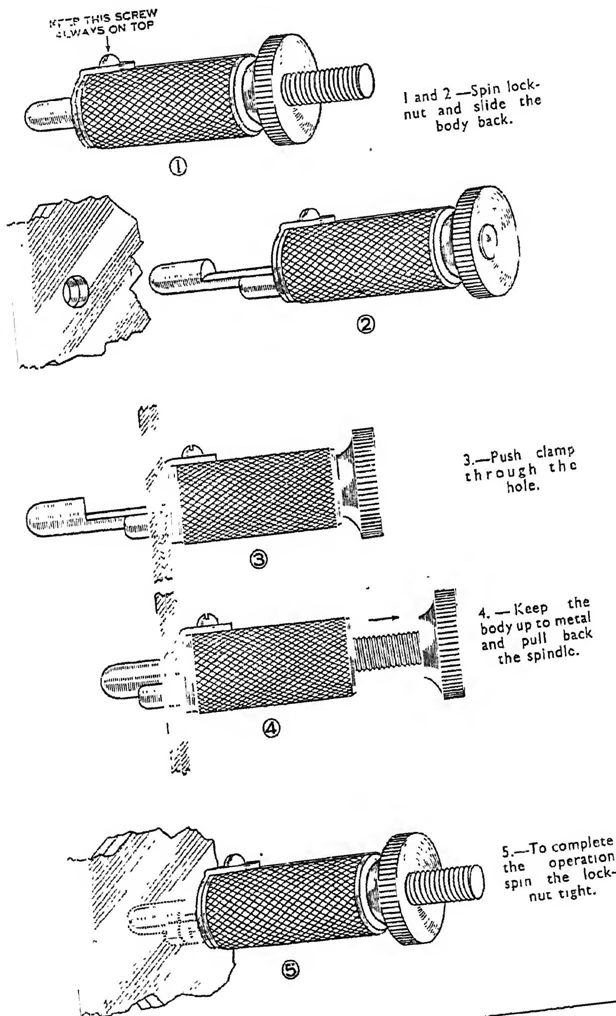


Fig. 5.—How the Myers riveting clamp is used, showing its locating and clamping action.

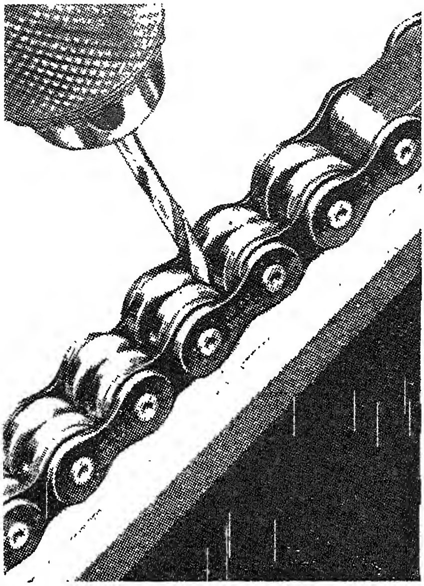


Fig. 6.—The Reynold jig chain in use as a drilling jig.

The machine is controlled by two foot pedals. On depressing one pedal the punch rises with the stripper, while the arm carrying the die swings round, bringing the die above the punch. The air valve is then automatically released, with the result that the piston-rod descends into the die, which is pushed down to the sheets arranged between the jaws of the machine. The stripper is thus depressed, and the punch forced through the layers of metal into the die. When the pedal is released the piston returns to its original position.

The other pedal is now depressed, with the result that the swinging arm is indexed. This brings the rivet shoe, which is split and spring-loaded to retain the rivet, into line with the punch. The air valve is again automatically opened, so that the piston-rod descends, engages the rivet shoe, and pushes it down until it is centred by the punch, which still projects slightly through the hole in the sheets. Before the rivet shoe touches the work its motion is arrested, but the piston still continues to descend and pushes the rivet through the shoe on to the punch, which is then withdrawn, allowing the rivet to pass through the hole. The rivet shoe is now indexed and the rivet head is formed on the underside by a further movement of the piston-rod.

Feeding the Rivets.—The rivets, which are loaded into a hopper, are tumbled by a drum, and only those rivets whose heads all point in the same direction enter the chute. At the bottom of the chute a slide, synchronised with the remainder of the cycle, selects one rivet at a time, which is allowed to drop through a tube

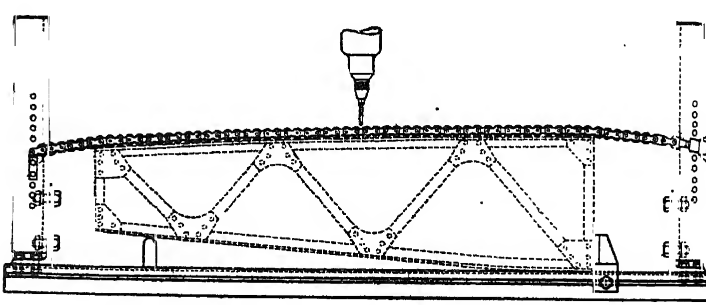


Fig. 7.—The jig chain in use for clamping and drilling an aeroplane rib.

into the rivet shoe at the appropriate moment.

Since a hold-up in production can occur if there is an unexpected shortage of one particular size or type of rivet, the majority of manufacturers emphasise the necessity for handling the rivets carefully, the loss of production time being, of course, a more important factor than the value of the lost rivets. Additionally, modern vacuum dust-collecting and separating equipment has been specially designed for aircraft work. The equipment, intended for cleaning the interior of aircraft components prior to painting, is designed, not only to pick up ordinary dust and dirt, but also to collect small rivets, bolts, and nuts. These are separated from the remainder of the dirt and delivered into a separate chamber for further use.

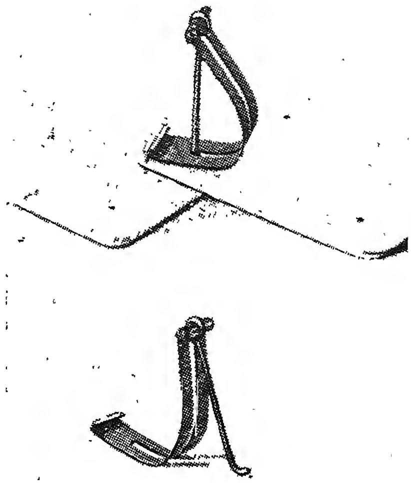


Fig. 8.—The General Aircraft rivet clamp is of the spring-bow type.

Method of Blind Riveting.—A method of blind riveting suitable for rivets up to ½-in. diameter, which is quicker and cheaper than using screwed rivets, is to drill a plain hole in the main member to which the second part is to be riveted and to a depth equal to twice the rivet diameter; a steel ball is then dropped in the bottom of the hole. The end of the rivet is deeply countersunk and the ball acts as an expander as the rivet is hammered home.

Ball diameter = ¾ rivet diameter. The depth of countersink is equal to the depth of the ball and the diameter of the countersinking is $\frac{1}{32}$ in. less than the diameter of the ball.

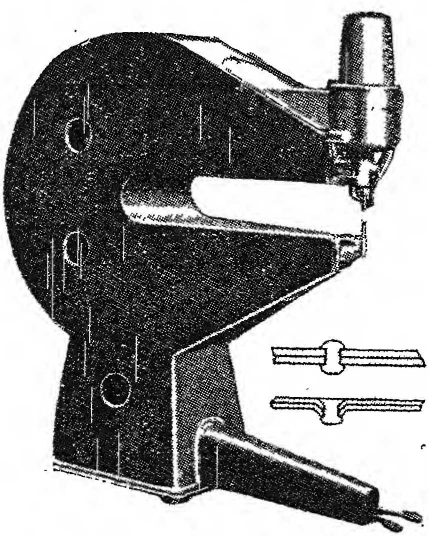


Fig. 9.—The Erco automatic machine for punching rivet holes, fitting and clenching the rivets.

Direct-squeeze Riveting.—Machines are of course used for direct-squeeze riveting, up to ⅛-in. diameter for duralumin or $\frac{1}{16}$-in. diameter for steel, whilst larger machines handle up to $\frac{5}{32}$-in. and ⅛-in. diameter in duralumin and steel respectively.

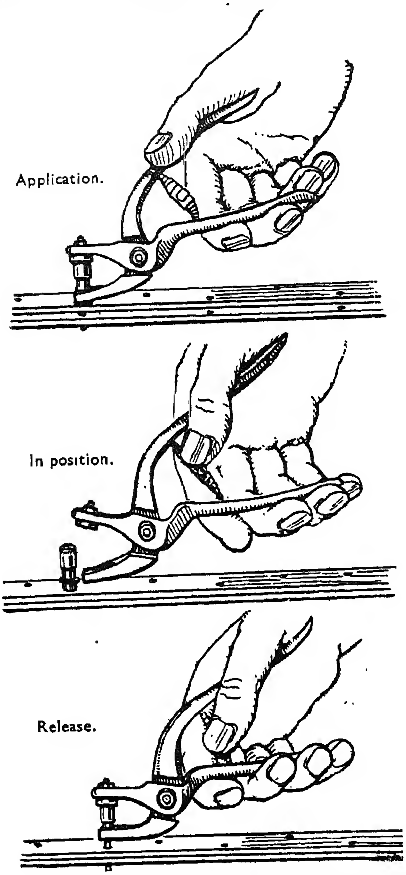


Fig. 10.—The Spencer riveting jig is fitted and removed with the aid of special pliers.

They are pneumatically operated, working on an air pressure of 80 lb. per sq. in. They embody an adjustable stock, which controls the stroke when riveting and can be set to give the desired squeeze.

Refrigeration for Duralumin Rivets.—One of the characteristics of duralumin is the change in physical properties which takes place under certain heat treatments. This change is a hardening effect which does not take place instantaneously, but which develops gradually over a period of about four days. Age hardening is accompanied by a considerable increase in tensile strength, and resistance to shock loading increases. If duralumin is to be cold worked softening at frequent intervals is generally required during the process of the work. If the metal has been hardened prior to cold working all the operations must be completed within two hours of the hardening, and this particularly applies to duralumin rivets. If used fully hardened, the rivet heads are difficult to form and may tend to show cracks at the edges. The general practice is to purchase and to store duralumin rivets in the annealed condition, and to harden them by heating to 950° C. and quenching immediately before use. The necessity for using the rivets within two hours after hardening can be overcome by using a refrigerant such as solid carbon-dioxide or dry ice for storage of the rivets after treatment to delay age hardening. Cooling of rivets must take place immediately after heat treatment. Special refrigerators have been produced for the storage of rivets and the storage period can be extended to three or four days, still retaining the ductility required for riveting. Previously the permissible storage time was for one to two hours at room temperature. A low-temperature quench tank is incorporated in the refrigerator itself, thus enabling the temperature of the metal to be reduced almost instantaneously and eliminating the ageing which would otherwise take place in an ordinary refrigerator during the period of time taken for the metal to cool to the temperature of the refrigerator. If the refrigerator is placed alongside the salt-bath shop the rivets can be cooled and stored immediately after heat treatment. These two features eliminate the uncertainty which is unavoidable when the heat-treated material is simply placed in a chilled atmosphere, even though air circulation may be induced by fans. A further advantage is that

salt-bath operators can now commence and stop work at the same time as the press operators. An internal temperature of $-10°$ F. to $-15°$ F., with an ambient temperature of 80° F., is maintained in a refrigerator. The usual capacity is about 3 cu. ft., and it will hold about 500 lb. of rivets at a filling. The condensing unit comprises a standard fractional-horse-power twin-cylinder compressor and $\frac{1}{2}$-in. solid-drawn copper cooling coils.

Explosive Rivets.—Where one side of the rivet is inaccessible, explosive rivets have been used with success, although the practice has been more widely adopted in America than in this country.

The rivet is set on the blind side by means of a small charge or explosive, inserted in a hollow end to the shank, the effect of the explosion being shown in Fig. 11. By careful control of the charge, which is solid, the shank can be held to an expansion of 0·02 in., the firing of the explosive being carried out by means of an electric iron. It is claimed that a man can set 15–20 rivets per minute, and seeing that there may be 800 " blind "-side riveting points in a fighter and up to 10,000 in a large bomber, the necessity for speed is clearly apparent. The expansion takes place in $1\frac{1}{2}$ to $2\frac{1}{2}$ secs. after the application of the silver-tipped iron, which, incidentally, weighs less than 5 lb. The rivets are of aluminium alloy, in various sizes, and are anodised. Bit stuffing is required to hold in the

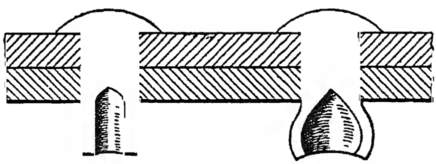


Fig. 11.—Showing the application of explosive rivets.

explosive, and one of the secrets of the success of this idea lies in the machinery by which a charge of sufficient accuracy is loaded into the shank cavity. The heads of the rivets are diecast.

Pressure at Jaws of Riveter.—Portable riveters as used on aircraft-component production are made as light as possible. The maximum load that can be developed at the jaws of a riveter depends upon:

(*a*) The maximum load at the operating handle.

(*b*) Adjustment of the jaws so that the rivet is closed just before the toggle reaches its most effective angular position.

(*c*) Elasticity of the jaws and the toggle mechanism.

(*d*) The lengths of the bell-crank lever arms.

Here (*a*) may be taken as about 15 lb.; (*d*) are about 10 in. and 1 in.

The elasticity is taken into account by a factor (*e*) which is equal to ratio load at the toggle pin to relative " spring " at that point. In this case this is estimated to be about 150,000 lb. per in.

The relation between force (F) at the jaw and force (f) at the handle is given in terms of the lengths (R and r) of the bell-crank lever arms by the approximate formula:

$$F = \frac{1}{2}\left(\frac{fR}{2}\sqrt{\frac{2}{1}}\right)^{\frac{2}{3}}$$

Where $F = \frac{1}{2}\left(\frac{10 \times 10}{2}\sqrt{\frac{150,000}{1}}\right)^{\frac{2}{3}} = 330$ lb.

On a rivet $\frac{3}{16}$ in. diameter this is equivalent to 64,000 lb. per sq. in. or about 28 tons per sq. in.

GRINDING

Structure of Abrasive Wheels.—In general, a grinding wheel is an aggregation of abrasive particles held together by a bonding material. The bonding material does not occupy all the space between the abrasives, but merely covers the grains. The bonding between grains is accomplished at the points of contact between the covered grains where the adjacent grain coverings become integral; thus the grinding wheel consists of a multiplicity of abrasive grains or cutting tools which are held more or less rigidly to the whole. The rigidity of the connection between the grains depends on the amount of bonding material and also upon the distance between the grains. Fig. 1 shows, in exaggerated form, the cutting action of an external grinding wheel. Fig. 2 shows ($\times$ 25) the resulting grind finish of a 60-grit wheel. Each projecting grit cuts a small groove in the work during its progress through its path interference. Visual smoothness is accomplished because the multiplicity of minute scratches seem to merge into one surface.

Grinding-wheel Grit, Bond, and Grade.—There are two types of abrasive grit material in general use for cutting metals: aluminium oxide (Al_2O_3) and silicon carbide (SiC). Emery and corundum are forms of aluminium oxide found in nature with varying degrees of impurities. Silicon carbide and aluminium oxide are manufactured by the use of electric furnaces, and are marketed under various trade names. Pure silicon carbide has a hardness of about 9·5 on the Mohs scale, while aluminium oxide is about 9. On this scale, diamond hardness has a value of 10, while cementite (FeC_3) is below 7.

The sieve method of separating the grits into size grades is employed after the abrasive is crushed, the pitch of the screen determining the size number of the grit. Thus a No. 60 grit must pass through a sieve whose wires are spaced 60 per inch. Sizes from 4 to 240 are measured by sifting through wire screen or silk, while smaller grits are designated " flour size " and are graduated by flotation in liquid.

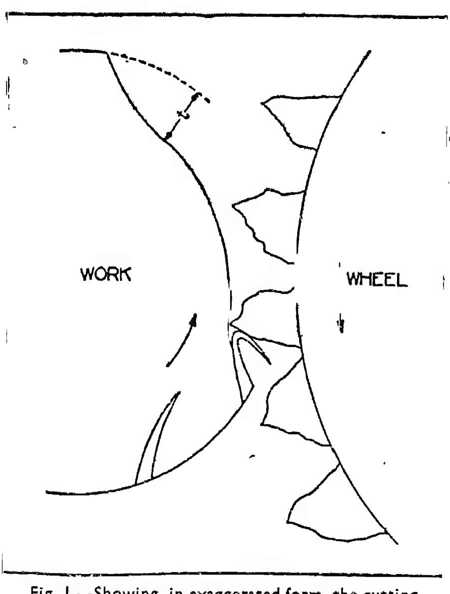


Fig. 1.—Showing, in exaggerated form, the cutting action of an external grinding wheel.

Many bond materials are in use to-day, vitrified, shellac, silicate, resinoid, and rubber being the most common. The vitrified process has the widest application because the resulting wheels are more porous, which permits chip clearance and consequent " cool cutting" properties. Rubber and resinoid are used where high wheel strength is necessary. The field of grinding presents such a wide variety of conditions that each of the above bonds is found to be applicable in some cases in preference to the others.

The grade of an abrasive wheel is determined by the ratio of bond material to grit material, while the term " structure " refers to grit spacing. Fig. 3 shows

a soft grading as compared with Fig. 3*b*. In each case, the grit spacing is approximately equal, but with different ratios bond to grit material. Fig. 3*c*, however, is a close structure as compared with Fig. 3*a* or Fig. 3*b*.

It is evident from the foregoing that the combinations of grits, grades, bonds, and structures are almost without limit. However, the exact choice of wheel is seldom necessary, since wheel action is very greatly affected by other conditions such as wheel speed, work speed, traverse rates, work diameter, wheel diameter, grinding fluid, and truing conditions.

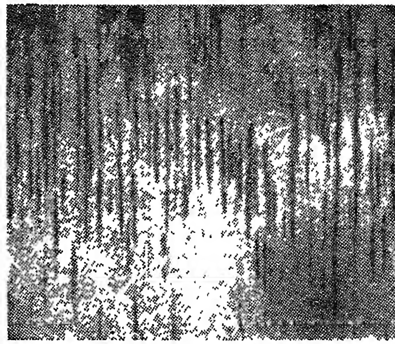


Fig. 2.—Finish produced (×25) by a 60-grit wheel. The multiplicity of minute scratches seems to merge into one surface, producing visual smoothness.

Guest's Grinding Theory.—Figs. 4 and 5 show the abrasives travelling relative to the work. The relative path of wheel to work is shown by the parallel paths. The time for one grit to reach a given point after the last one passes that point is :

$$(1)\ \frac{1}{NV} = \text{time}$$

where $\frac{1}{N}$ = pitch of grits

V = velocity of grits.

The normal velocity v_1 (Fig. 4) and v_2 (Fig. 5) multiplied by the time equals the chip thickness d, thus :

$$(2)\ \frac{v_1}{VN} = d_1.\ \frac{v_2}{VN} = d_2.$$

But from the relative velocity diagrams :

$$(3)\ v_1 = v \sin (A - B),$$
$$v_2 = v \sin (A + B).$$

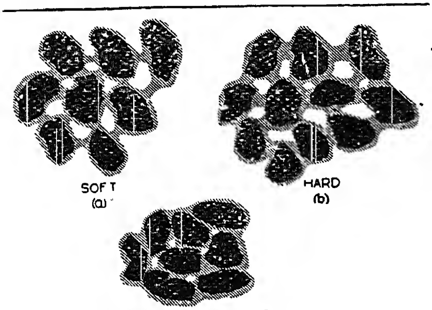


Fig. 3.—Illustration of ratio of bond material to grit material, and of grit spacing. (*a*) Soft grade, (*b*) harder grade. Grit spacing is the same as shown at (*a*), but ratio of bond to grit material is different. (*c*) Close structure compared with (*a*) or (*b*).

Since the angle B is very small, this angle can be neglected, thus :

$$(4)\ d = \frac{v \sin A}{VN}.$$

Fig. 6 shows the application of this principle to external cylindrical grinding. The time for succeeding grains to pass a point is again :

$$\text{time} = \frac{1}{NV}.$$

The normal velocity is :

$$v_1 = v \sin (C + D).$$

Therefore :

$$(5)\ d = \frac{1}{NV} v \sin (C + D).$$

It is obvious that this result can be obtained without resort to relative velocities.

By the use of the cosine law, the cosine (C + D) can be obtained in terms of the depth of cut $\frac{t}{2}$ and the radii R and r: If the cos (C + D) is expanded into a series of angles (C + D) is found approximately in terms of R, r, and t. Thus:

$$(6)\ \text{Cos}\ (C + D) = 1\frac{R + rt}{Rr\ 2} + \frac{t^2}{8Rr}\ \text{(Cosine law)}.$$

$$(7)\ \text{Cos}\ (C + D) = 1\frac{(C + D)^2}{2} + \frac{(C + D)^4}{24}.$$

$$(8)\ \text{Therefore,}\ (C + D)^2 = \frac{R + r}{Rr} \cdot t.$$

Since angle (C + D) is small sin (C + D) is assumed to be equal (C + D) (Radian measure) substituting in (5).

$$(9)\ d = \frac{v}{VN} \cdot \sqrt{\frac{R + r}{Rr} \cdot t}.$$

The term d is for maximum chip thickness. A further hypothesis is that the maximum chip area varies as the squares of the maximum chip thickness when the grain is assumed to be roughly triangular in shape (Fig. 8). Thus:

$$(10)\ d^2 = \frac{v^2}{V^2N^2} \cdot \frac{R + r}{Rr} \cdot t.$$

This theory then assumes that the force acting on the grain is proportional to d^2. Therefore, the tendency for grains to break or dislodge will vary with the quantity.

$$(11)\ \frac{v^2}{V^2N^2} \cdot \frac{r + R}{Rr} \cdot t.$$

A similar analysis for internal grinding will result in the expression:

$$(12)\ \frac{v^2}{V^2N^2} \cdot \frac{r - R}{Rr} \cdot t.$$

The conclusion of the theory therefore is that the ratio of work velocity to wheel velocity $\frac{v}{V}$ has a large influence on wheel action, while the depth of cut has a direct effect. For large wheels with small work, the wheel diameter has little influence, while work diameter has a large effect. In internal grinding the velocity ratio and depth of cut affect wheel action in similar manner, while the wheel diameter variations will in most cases have a greater effect than work diameter variations.

Alden's Theory.—Referring to Fig. 6, it was noted previously that the quantity "d" can be obtained by direct geometrical considerations (see small insert triangle). Mr. George Alden presented a paper to the A.S.M.E., in which the grain depth of cut theory was proposed. His formula is:

$$(5)\ d = \frac{v}{VN} \sin\ (C + D)$$

which is in agreement with Guest equation 5. However, the term sin (C + D) was tabulated in terms of wheel diameter, work diameter, and depth of cut. The tabulated values in Alden's work check very closely with calculated values from Guest's formula.

Alden's theory assumes that wheel action (force on grain) varies as the "grain depth of cut."

Hutchinson's Theory.—In December 1937 Roland V. Hutchinson presented a paper to the S.A.E. which appeared in the *S.A.E. Journal* in March 1938. Mr. Hutchinson's excellent presentation of the entire subject of grinding includes consideration of work heating, chip formation, coolant, dressing, and cam grinding. A mathematical derivation of an expression for average chip thickness was deduced. This derivation differentiates between the condition of the so-called up-cut and down-cut (in down-cut, the work travels opposite to the wheel at the point of contact; up-cut the work travels with the wheel). Fig. 7 shows the geometrical method of attack. In this method the wheel is regarded as rotating around the work at an angular speed equal to the work speed. To obtain this

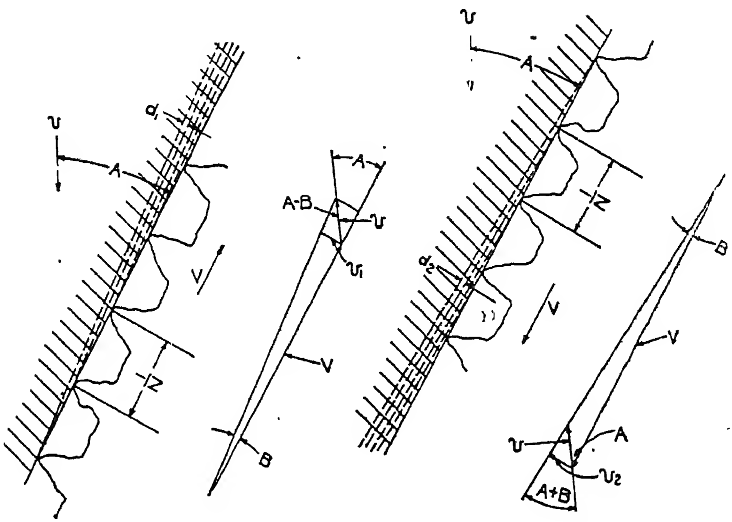
result geometrically, a rolling circle is placed on the wheel centre in contact with a track circle. The relation of these circles is given by:

$$(13)\ \frac{f}{g} = \frac{n}{N} = \frac{D}{E}$$

where n = work speed r.p.m.
N = wheel speed r.p.m.
The length of chip is derived in this paper as:

$$(14)\ L = \left(R \pm r\frac{n}{N}\right) \frac{Rr}{R(R + r)}.$$

The plus sign is for up-cut and the minus is for down-cut. Using the assumption that rD times $\frac{t}{2}$ is the volume of chip, and dividing this value by L, the average



Figs. 4 and 5.—Diagrams showing path followed by abrasives relative to work.

length of chip, the result is the average chip approximately assuming the chip is triangular in shape. The equation for average chip thickness will then be:

$$(15)\ d = \frac{rn}{RN + rn} \cdot \frac{t}{2}.$$

The term r in the numerator was omitted in Mr. Hutchinson's paper. However, for dimensional consistency, this term is necessary and a check of his derivation showed the point at which it was dropped. Since the angle D is the rotary movement of the wheel axis while a point on the wheel is moving the distance L, the assumption is that grits have spacing of L distance. To accommodate the formula to other grit spacings, such as $\frac{1}{n}$ as indicated in Guest's and Alden's work, the angle should be modified as follows:

$$(16)\ D1 = D \cdot \frac{1}{nL}.$$

If this value is used in Mr. Hutchinson's derivation and if the effect of down and up cut is neglected the result will be

$$(17)\ d = \frac{1}{2}\ \frac{v}{Vn}\cdot\frac{R + r}{Rr}t$$

which is one-half the value obtained by Guest for the maximum chip thickness, proving that the bases of the derivations are in agreement. Mr. Hutchinson's theory contains other valuable contributions to the theories of grinding, such as equation for average chip thickness for surface grinding and modifications of the plunge-cut formula (15) for traverse grinding, which shows that the length of chip varies according to the equation:

$$L1 = \sec(H) \cdot L$$

where L = plunge cut chip length
L1 = traverse chip length
(H) = helix angle of feed on work.

Note: In centreless grinding, (H) would correspond exactly to the regulating wheel feed angle.

Krug Theory.—In September 1925 an analysis of the geometrical consideration of grinding by Dr. C. Krug was published. His simplified formula for maximum chip thickness is given for plunge-cut external grinding as:

$$(18)\ d = \left(\frac{2R}{r} + 1\right)\frac{v}{V}\frac{rt}{2}$$

all notations being the same as previous formulæ. However, later experiments in Germany and elsewhere showed the errors in Dr. Krug's derivations, and further showed that values obtained with Krug's formula were of a different order from those obtained with Guest formula. Further, the assumption in Krug's formula is that the grit spacings are equal to one-half the arc of contact.

In his reply to Hoffman, Krug points out the chip thickness is not as important as the plastic flow conditions obtained when the chip is formed.

Dr. Krug has analysed the structure of grinding wheels. In his analysis the grains are regarded as spherical in shape. He shows that the grains can be packed in some manner between two extremes, i.e. where the centres of the contacting grains are disposed on the corners of a cube or where the centres of the grains are placed on the corners of a tetrahedron. From these assumptions the analysis shows that the grits can only occupy from 52 to 56 per cent. of the total volume. However, according to Krug, the remaining space cannot be occupied entirely by bond, since clearance space for chip formation must be provided. He arrives at the conclusion that each grit must have only a coating of bond (Fig. 3). With grits in contact, Dr. Krug analyses the force to dislodge a grit for various thicknesses of coating where the grits contact and grit coats merge to form a bond.

For bending the ratio of resistances to fracture for two layer thicknesses S_1 and S_2 is:

$$(19)\ \frac{W_2}{W_1} = \left\{\frac{S_2^2 + 2dS_2}{S_1^2 + 2dS_t}\right\}^{3/2}$$

where d = diameter of grit.
S_1 = thickness of bond layer for W_1.
S_2 = thickness of bond layer for W_2.
$\frac{W_2}{W_1}$ = ratio of resistance to bond fracture.

For the case of fracture in tension:

$$(20)\ \frac{R_2}{R_1} = \left\{\frac{S_2^2 + 2dS_2}{S_1^2 + 2dS_t}\right\}^2$$

where $\frac{R_2}{R_1}$ is the ratio of resistances to fracture for the two-bond layer thickness S_1 and S_2.

The failure of the bond in shear is not treated, although it is obvious each exposed grain will have five or more bonding contacts. When a grit breaks out, these bonding contacts must all fail in bending, compression, tension, shear, or combinations of these.

The study of grinding is one of transients. The grinding operation consists of thousands of individual events, few of which are exactly similar to each other, but which integrate into a statistical summation. The target of the theories is the statistical average of these events. Although the implications of the theories are borne out in practice in a qualitative way, experimental data are lacking to determine whether the theories are even roughly quantitative.

It is quite obvious that the cutting grains of a wheel are extending at every conceivable distance within the limit of the depth of cut. Fig. 9 shows a photomicrograph of a surface which is partly superfinished, illustrating the variation in depth of cut of individual grains.

Hans Ernst made a detailed study of chip flow. In this all metal-cutting chips are divided into three types. The second type, called the "continuous chip with continuously escaping compressed layer adjacent to the tool face," would seem to be the most likely to occur in grinding because of the high speeds and shallow depths of cut. On the other hand, when it is considered that negative rake angles at the cutting points are inevitable, the third type, i.e. built-up edge type, would appear to be the more probable. Mr. Ernst shows most conclusively that when these built-up edge conditions are encountered, the result is a very ragged

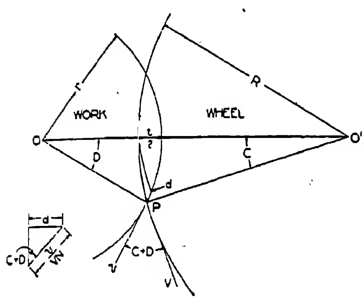


Fig. 6.—Showing application of formula to external cylindrical grinding.

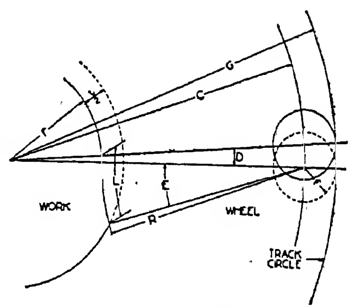


Fig. 7.—Diagram showing principle of geometrical method of attack.

finish. However, the cutting grains are very narrow and the probability of chip flow sidewise alters the whole aspect of rake angles. Fig. 10 shows a photomicrograph of grinding chips which apparently have type 2 characteristics.

Fig. 11 shows several random grinding-chip sections. The large section is remarkable because its shape is approximately that of the geometrical configuration determined by the theories. The central chip in Fig. 12 shows distinct segments which for a ductile material indicates the type 3 or "built-up edge" type.

The Universal Grinding Machine.—Fig. 14 shows a front elevation of a Brown and Sharpe universal grinder; it shows also the overhead driving gear. This machine traverses the work past the grinding wheel, the latter being driven by a belt which passes over a flanged pulley connected to the wheel spindle on to the driving pulley of the overhead shaft.

The table, which is arranged to move backwards and forwards automatically, has a headstock and a tailstock in which centres are provided to carry the work being ground. An important feature of this machine is the automatic cross feed, which enables the operative to deal with other work while the grinding operation proceeds and, by uniform movements, maintains the grinding wheel in proper condition and increases its "sizing power"—a matter of great convenience where a number of pieces of work are to be finished to the same dimensions.

The automatic cross feed is shown in Fig. 15, from which it can be seen that the reverse lever 1 is operated by dogs 2 and 3 and causes the motion of the table to reverse automatically. Alternatively, it can be quickly operated by hand when

it is necessary to reverse the table between the predetermined points of travel set by the dogs. The lever 4 is raised by a spring, which is enclosed in the tubular case at the back of the ratchet 5.

Mounted upon the reversing shaft bearing is an auxiliary lever 6 which operates lever 4 through the cam and roll 7 which, in turn, operates the pawl 8. The movement of this pawl is controlled by adjusting screws 9 that bear against the surface at the bottom of lever 6, and this acts as a stop to limit the upward movement of lever 4. As it is often desirable to have a coarser feed at one end of the stroke than at the other, two adjusting screws are provided for this purpose, i.e. to vary the stroke at each end as desired.

Provision is also made whereby the dogs can be raised and the table run beyond the reversing points without disturbing the adjustment, and this is arranged in such a manner that when released, the dogs readjust themselves and thus prevent the table from accidentally running beyond the reversing points and perhaps injuring the work.

Using the Automatic Cross Feed.—(1) Adjust the travel of the table and with the work and wheel revolving and pawl 8 at B, carefully turn handwheel 10 in the direction indicated by the arrow until the wheel just cuts the work. Now the handwheel is left in this position and the travel of the table is stopped.

(2) Pawl 8 is now swung back into position towards the rim of the handwheel, latch 11 is raised, and the head carrying this latch around on the graduated ratchet 5 is moved until the point of the throw-out shield 12 has just passed the tooth occupied by pawl 8. Latch 11 is now allowed to engage the ratchet teeth.

(3) Pawl 8 is now thrown into position where it will rest against the throw-out shield, and the table is started up ; if the pawl fails to engage with the ratchet, the handwheel must be moved a little by placing the forefinger of the right hand against A and the thumb on latch 13. Without moving the wheel, pinch the latch once and notice what effect it has on the cut ; when pawl 8 has moved the feed sufficiently to cause the wheel to show a cut, the machine should be allowed to run until the cut is practically ended, when the stroke of the table should be stopped at the footstock end, using the shipper lever at the front of the machine.

(4) Now the diameter just ground should be measured, ascertaining the thousandths and quarter-thousandths to be ground off the diameter, and latch 13 pinched once for each quarter-thousandth. If, for instance, you have to take off 0·002 in., then the latch must be pinched eight times, but if the amount to be taken off is large, knob 11 should be lifted and the wheel set by means of the graduations.

Start the table up and pawl 8 will move the graduated ratchet until the shield prevents the pawl from engaging another tooth. As the wheel will show a cut after the cross feed is thrown out, the cut should be allowed to continue until it shows the same as when the first measurement was taken, stopping the table at the footstock end as before.

If a suitable wheel is used (which will be explained later), the work will now show a reduction of 0·002 in. diameter as required. When the operation is completed, pawl 8 is thrown out and, without changing the position of latch 11, the handwheel is turned about one revolution in the opposite direction to that indicated by the arrow.

Feeding by Hand.—The ratchet can, if desired, be used to feed by hand, in which case the head carrying latch 11 must be moved to the left until it engages stop 14 (operated by handle 15). Latch 13 is then pinched once for each quarter-thousandth to be removed as before, and the handwheel advanced until the head again engages the stop.

New Blanks.—When the fresh blank has been placed on the machine and the stroke of the table started, the handwheel must be turned in the direction indicated by the arrow until the wheel just cuts the work, when the pawl is thrown into mesh. Allow the table to continue its stroke after the shield has thrown out the feed and the wheel shows the same cut as before. Stop the table as before, measure the diameter of the work, pinch latch 13 as many times as the work is quarter-thousandths oversize and proceed with the cut.

To obtain the diameter produced by the action of the cross feed, one should always measure when the wheel is practically through cutting ; the wheel will cut from the diameter of the work after the cross feed has stopped, and may show a few sparks after it has practically finished cutting.

See also our advertisements on pages cxv, cxxiii, cxli, cxlix and clxix.

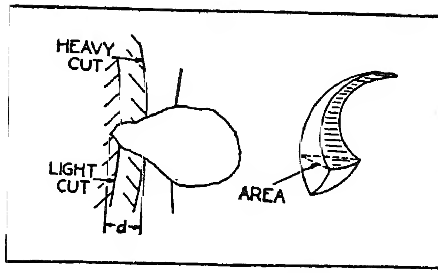


Fig. 8.—Diagram showing hypothesis (Guest) that maximum chip area varies as the squares of the maximum chip thickness when the grain is assumed to be roughly triangular in shape.

Grinding Wheels.—The substances chiefly used as abrasive materials in the manufacture of grinding wheels are emery and corundum. Rock emery stone, found in various parts of the world in a natural state, is really an inferior form of corundum, often containing a large content of iron. This rock emery stone is crushed to various degrees of fineness, and the resulting grit is mixed with rubber or shellac and then compressed. Such wheels are known as composition wheels and are very useful for form shapes.

A more ideal grinding wheel is the vitrified type, in which the required grade of powdered corundum is mixed with cement or clay and baked by means of steam. The heat causes certain changes of " bond " which results in the mixture taking on a glassy form, yet with some degree of abrasiveness. It is also caused to contract, and this leaves the wheel porous so that the content of grit on the surface projects slightly but is yet held sufficiently firm to keep it in position until entirely worn away by use. This tenacity is termed the " grade " of the wheel, and is varied by the nature and quantity of cement used in the making of the wheel.

Wheel Grading.—Wheels are known as " very soft," " soft," " moderately soft," " medium," " moderately hard," " hard," and " very hard," the size of the grit particles being generally denoted by a number which corresponds with the number of squares per inch in the sieve through which the grit has passed. The method of grading now in general use and introduced by Messrs. Alfred Herbert, of Coventry, is a simple system whereby the degree of hardness is denoted by letters from J to M—M being the hardest wheel and J the softest.

To obtain the greatest efficiency in grinding, it is essential that wheels of suitable hardness and grit should be used, and in this respect the following table will be found to suit most requirements.

	Grade	*Grain*
For stiff pieces of machine steel up to $2\frac{1}{2}$-in. diameter –	M	24
For slender or large-diameter pieces of machine steel –	L	24
For hardened steel up to $2\frac{1}{2}$-in. diameter – – –	K	24
For hardened steel over $2\frac{1}{2}$-in. diameter – – –	J	24
For high-carbon steel – – – – – – –	L	24
For cast iron over $2\frac{1}{2}$-in. diameter – – – –	J	24
For bronze alloys – – – – – – –	L	24
For cast iron up to 1-in. diameter – – – –	K	24

For general purposes a wheel of coarse grit is preferable and, generally speaking, it is true to say that the harder the material to be ground the softer must be the bond and the finer the grit of the wheel used. The diameter of a wheel has no effect on the efficiency or output of the machine and a 6-in. wheel will do just as much work in a given time as will a 12-in., but large wheels are, in fact, more economical than small wheels, because the cost per cubic foot is larger in small wheels than it is in large ones.

When a selected wheel proves to be too hard, causing it to glaze quickly, then a softer wheel should be tried (for instance, if a grade M is too hard, try a grade L), but when a wheel appears to be unsuitable for a particular job, it can often be made more efficient by changing the speed. If the work becomes overheated, this indicates that the wheel is too hard, but an increase of work speed can often eliminate this overheating, although where this is not effective then a grade softer wheel must be resorted to.

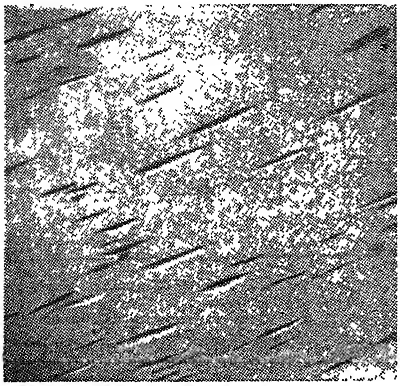


Fig. 9.—Photomicrograph of surface partly superfinished, showing variation in depth of cut of individual grains.

If, instead of overheating, the trouble takes the form of the grinding wheel crumbling and wearing very rapidly, then a slow speed will often enable it to stand up to the job better, but here again, if the trouble is acute, one must resort to a harder-grade wheel. Work diameters are a matter of considerable importance in the selection of suitable grinding wheels; a wheel working perfectly satisfactorily on a small-diametered work-piece may be quite inefficient on a larger work-piece. The reason for this is, of course, that the area of contact is greater, and the greater the contact area the softer must the wheel be. It is for this reason that in the table given above, a grade M wheel is recommended for work diameters of up to 2½ in., whilst for anything over that, grade L (the next softer grade) is recommended.

Truing Wheels.—It is, of course, necessary to true up the grinding wheels at various times, and this is best done by means of a diamond. This is held in a suitable tool fixed rigidly to the machine, the wheel being rotated in the same plane and at the same speed as when normally grinding. In carrying out this work, a large number of light cuts (say 0·001 in. deep) are much preferable to a few heavy cuts. The position for the diamond turning tool is shown in Fig. 16, which also shows the necessary provision for water cooling.

Speeds and Feeds.—The points which have to be taken into consideration in setting up a grinding job are as follows:

(1) Speed of the work.
(2) Speed of the grinding wheel.
(3) Depth of the cut.
(4) Length of travel.
(5) Water supply.

(1) The speeds recommended by various manufacturers of grinding machines vary considerably, between 25 and 60 ft. per minute, but it may be taken as axiomatic that too slow a speed will cause overheating of the work, while too high a speed will cause vibration. If, when grinding is in progress, it is found that the wheel is wearing rapidly, then the work speed should be decreased; where, on the other hand, the wheel is found to glaze quickly, then that is a sign that the work speed should be increased.

(2) The best cutting speed for grinding wheels is usually considered to be about 6,000 ft. surface speed per minute; lower speeds, especially under 5,000 ft., are found to cause excessive wear.

(3) The depth of the cut or feed of the wheel naturally varies with the general conditions and the class of work being ground, but in all cases the feed should operate at each end of the stroke. For roughing work the cut may be as deep as 0·004 in. to commence with, but as the

Fig. 10.—Photomicrograph of grinding chip of "continuous" type.

work progresses the depth of cut should be gradually decreased so that it finishes off with only about 0·0005 in. depth.

(4) One of the most important considerations in grinding is the table feed; the width of the grinding wheel largely determines the distance of table travel. It can be estimated as follows: For roughing work the distance between the ends of the stroke may be taken as a length equalling two-thirds of the width of the wheel for each revolution of the work, but for finishing, the factor of the width of the wheel should be reduced to less than one-half.

(5) So far as water supply is concerned, it is, in fact, impossible to provide too much where grinding is being done, but somewhere around 8 gallons per minute is usual.

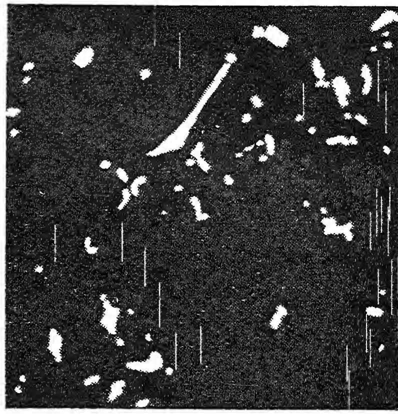


Fig. 11.—Photograph of random grinding-chip sections.

Chattering.—This is one of the most common faults met with in grinding operations and is usually due to lack of rigidity in the machine itself, to the rotation of the work being too rapid, or to the grinding wheel itself being out of truth. Long, slender work is particularly liable to this form of trouble, and such work should always be supported by a steady rest to damp out any vibration. If the wheel is not true, then it should be first turned up by taking a cut along in the lathe.

Preparing Grinding Work.—There now remains the question of how much stock to leave for grinding, and this may be anything between 0·015 in. and 0·125 in., which allows the turning to be done on a coarse feed. If the amount of metal to be removed exceeds $\frac{1}{16}$ in., then it is better to rough turn the job, and where keyways are to be cut, here again the rough turning should be done before the keyways are cut and before the grinding is commenced.

In Fig. 17 is shown a chart which is in common use and which indicates the correct allowances for various kinds of work and for various diameters. The curves marked 1 and 1A indicate the maximum and minimum amounts to be left on the diameter of a rough-turned job over twelve times its own diameter in length. This means that for a shaft 3 in. in diameter and over 3 ft. in length it should be turned from 0·035 in. to 0·050 in. oversize, whereas for a shaft of 6 in. with a length of over 6 ft. the oversize dimensions would be from 0·060 in. to 0·080 in. with a traverse of 16 in., this allowing a turning limit of 0·020 in. and, apart from a coarse traverse, making things simpler in the turning shop.

The curves marked 2 and 2A indicate the maximum and minimum amounts oversize rough turning for work less than twelve times the diameter in length. When the work is produced by the use of box tools on a bar turret lathe, or where it is necessary to prepare work for grinding by turning with a fine traverse, then the allowances shown by curves 3 and 3A and 4 and 4A are correct, the former being the oversize dimensions to be left on the diameter of smooth-turned jobs of more than twelve

Fig. 12.—The central chip shows distinct segments which for ductile material indicates the "built-up edge" type.

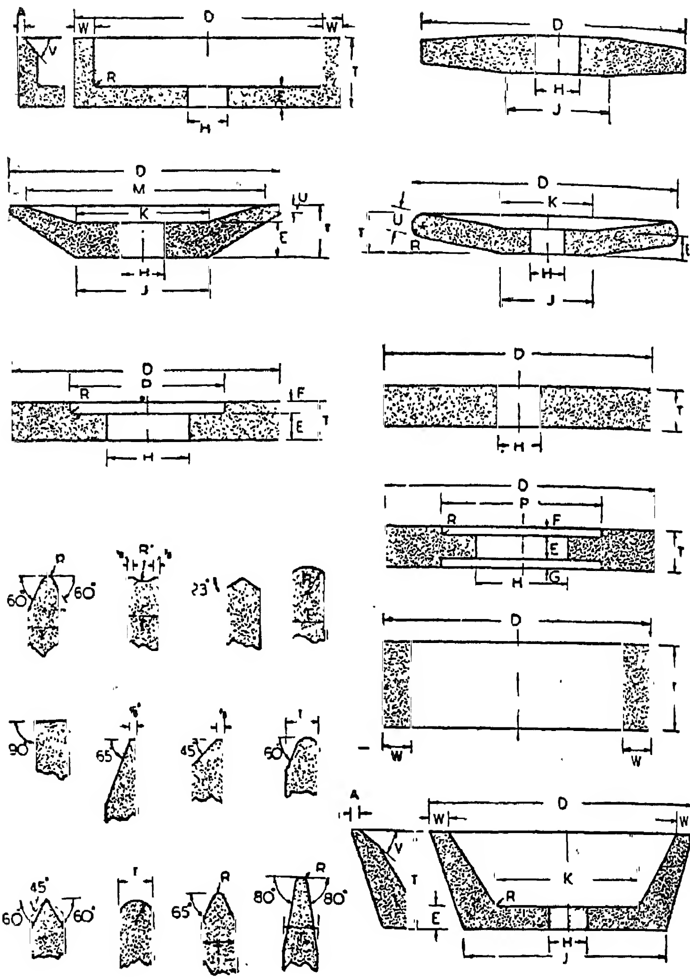


Fig. 13.—Standard grinding-wheel shapes.

A—Flat spot of bevelled wall. D—Diameter (overall). E—Centre of back thickness. F—Depth of recess (see Type 5). G—Depth of recess (see Type 7). H—Arbor-hole diameter. J—Diameter of flat or small diameter. K—Diameter of flat inside. M—Large diameter of bevel. P—Diameter of recess. R—Radius. T—Thickness (overall). U—Width of face. V—Angle of bevel. W—Thickness of wall.

times diameter in length, and the latter being the same but for lengths of less than twelve diameters.

Work which is to be case-hardened must be turned with a reasonably smooth finish so as to obtain regular penetration of the casing compound, and conse-

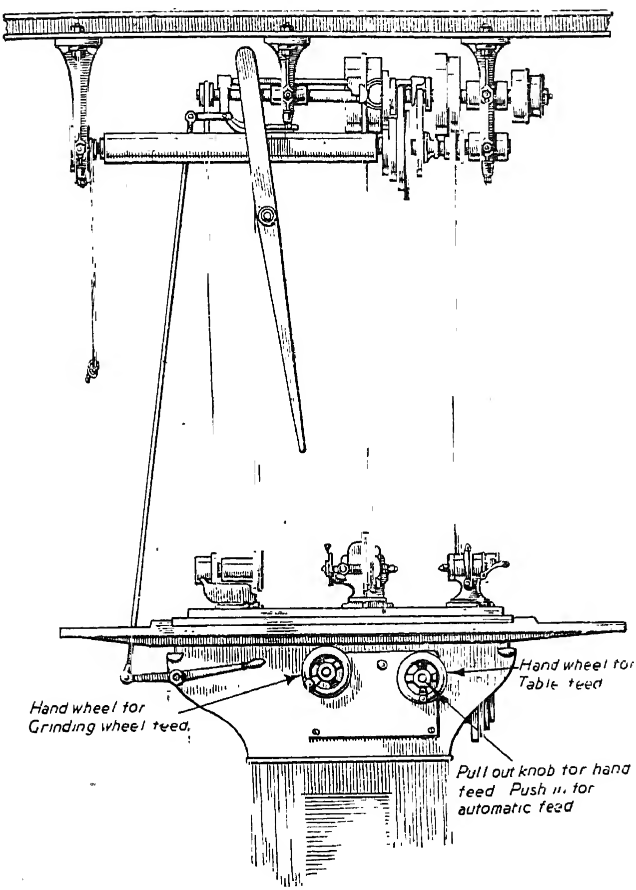


Fig. 14.—Front elevation of Brown and Sharpe universal grinder, showing overhead gear.

quently the allowances indicated by curves 3 and 3A should be used for case-hardening work regardless of its length.

Where such work is hollow it may easily distort after quenching, and this calls for great care in the hardening ; if the allowances specified are exceeded, the hard skin will be entirely removed in grinding to size. Allowances for high-speed steel and carbon work which is to be hardened will be the same as for soft work, as any

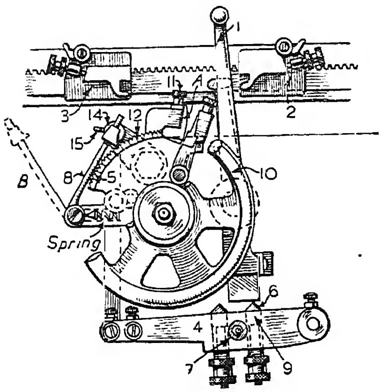


Fig. 15.—Automatic cross-feed gear on universal grinder.

distortion which occurs must be corrected in the straightening press before grinding.

Lapping.—A surface which has been finished by grinding may not always be quite accurate enough for some classes of work or may not have quite good enough a surface. Such articles as standard gauges, and in some cases the journals of shafts, are lapped after grinding. Lapping is therefore an additional abrasive process for getting a still finer finish than can be obtained by grinding.

These laps are made from soft cast iron, brass, copper, or lead; the lead laps being easy to make, quickly renewed, and, if cast on a tapered mandrel, can be easily expanded. Copper, in fact, holds the abrasive material better than anything else, and is therefore most suitable for a considerable degree of finishing if necessary, but in any case the lap must always be of softer metal than the metal being lapped.

The abrasive materials most commonly used for the purpose are fine-ground glass, flour of emery, and diamond dust. To charge a cylindrical lap the abrasive paste is spread over the surface of a flat steel plate, and the lap is then rolled over the plate until the abrasive has become sufficiently bedded in the lap. In the case of a ring lap the abrasive is best spread on a steel mandrel of smaller diameter than the hole in the ring and then rolled into the lap.

There are, of course, several other types of grinding machines which we have not been able to describe in this article, such as the surface grinder, for instance, which is used for work such as finishing piston rings, saws, milling cutters, thrust collars, discs, etc. In this type of machine the crosshead carrying the wheel slide is usually adjustable so that surfaces may be finished perfectly flat, concave, or convex as desired. Such a grinder, when fitted with a magnetic chuck, will grind the thinnest possible work and is usually suitable for either wet or dry grinding.

Then there are various grinding machines designed for special purposes, such as Bayer, Peacock and Co.'s machine for grinding locomotive crankpins. This machine produces a dead smooth finish, the surface being concentric with the original centre, and the amount of metal removed being the minimum necessary to produce a true crankpin.

There is also the automatic radial grinder, designed for work such as thrust washers, ball bearings, and spherical joints. This machine produces work with the high degree of accuracy and mirror-like finish needed for ball-bearing houses and similar work. In this machine the radial arm carrying the workhead is pivoted on ball journal bearings, ball bearings supporting the weight of the oscillating parts, and provision is made whereby the automatic oscillations can be instantly stopped and started independent of other movements.

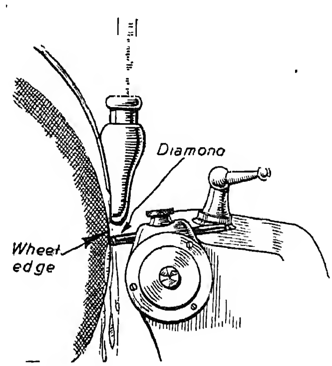


Fig. 16.—Truing a grinding wheel with a diamond cutter.

GRINDING-WHEEL SPEEDS

High-speed Table						Low-speed Table					
Diameter of Wheels		7,000 S.F.P.M.	8,000 S.F.P.M.	9,000 S.F.P.M.	10,000 S.F.P.M.	Diameter of Wheels		4,000 S.F.P.M.	5,000 S.F.P.M.	6,000 S.F.P.M.	6,500 S.F.P.M.
in.	*mm.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*in.*	*mm.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*
1	25·4	26,738	30,558	34,377	38,197	1	25·4	15,279	19,098	22,918	24,828
2	50·8	13,369	15,279	17,189	19,098	2	50·8	7,639	9,549	11,459	12,414
3	76·2	8,913	10,186	11,459	12,732	3	76·2	5,093	6,366	7,639	8,276
4	101·6	6,684	7,639	8,594	9,549	4	101·6	3,820	4,775	5,729	6,207
5	127	5,347	6,111	6,875	7,639	5	127	3,056	3,820	4,584	4,966
6	152	4,456	5,093	5,729	6,366	6	152	2,546	3,183	3,820	4,138
7	178	3,820	4,365	4,911	5,457	7	178	2,183	2,728	3,274	3,547
8	203	3,342	3,820	4,297	4,775	8	203	1,910	2,387	2,865	3,103
10	254	2,674	3,056	3,439	3,820	10	254	1,528	1,910	2,292	2,483
12	305	2,228	2,546	2,865	3,183	12	305	1,273	1,591	1,910	2,069
14	356	1,910	2,183	2,455	2,728	14	356	1,091	1,364	1,637	1,773
16	406	1,671	1,910	2,148	2,387	16	406	955	1,194	1,432	1,552
18	457	1,485	1,698	1,910	2,122	18	457	849	1,061	1,273	1,379
20	508	1,337	1,528	1,719	1,910	20	508	764	955	1,146	1,241
22	559	1,215	1,389	1,563	1,736	22	559	694	868	1,042	1,128
24	609	1,114	1,273	1,432	1,591	24	609	637	796	955	1,034
26	660	1,028	1,175	1,322	1,469	26	660	588	734	881	955
28	711	955	1,091	1,228	1,364	28	711	546	682	818	887
30	762	891	1,018	1,146	1,273	30	762	509	637	764	828
32	813	835	955	1,074	1,194	32	813	477	597	716	776
34	863	786	899	1,101	1,123	34	863	449	562	674	730
36	914	743	849	955	1,061	36	914	424	530	637	690

Another machine which should be mentioned is the hole-and-link grinder designed for grinding marine and other very large expansion links; also holes in case-hardened steel details can be trued accurately and conveniently. This machine will grind holes from $\frac{3}{4}$-in. to 5-in. diameter, the grinding spindle revolving at 1333 revolutions per minute with a vertical traverse of 8 in. and a maximum eccentricity of $\frac{1}{2}$ in. The drive is through the medium of a $4\frac{1}{2}$-in. driving pulley 3 in. wide, and needs 5 h.p. to drive it.

The turret grinding machine is another which must be mentioned, as it bears a similar relation to the plain or universal grinder as does the turret lathe to the ordinary sliding, surfacing, or screw-cutting lathe. It usually carries three grinding wheels, two of them usually heavy wheels for external work and the third for internal grinding. The advantages are, of course, that it eliminates the time spent in changing over from external to internal work with its consequent

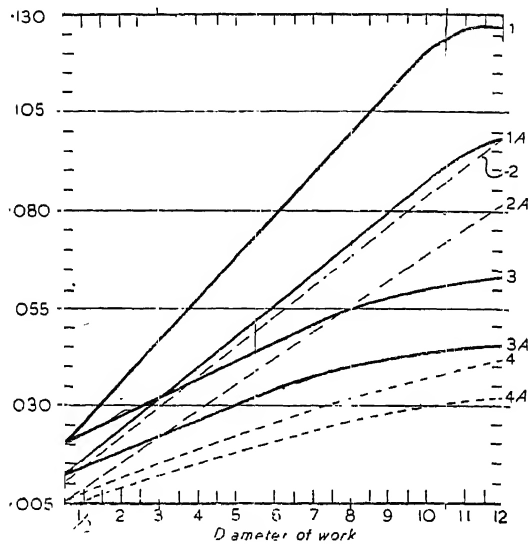


Fig. 17.—Chart showing maximum and minimum oversize for shafts to be ground to size.

lengthening and shortening of belts, and also ensures that the various surfaces when ground are in correct relationship with each other.

The main spindles carry a disc wheel suitable for cylindrically grinding shafts and similar work, and, secondly, they may carry a cup wheel for side or face grinding of flanges, etc. Where the cup wheel is not required it can be taken off and a disc wheel fitted of the same size as that carried on the first spindle, thus making possible the use of both roughing and finishing wheels on work where a high finish is necessary. Alternatively, wheels of different grades can be fitted for grinding different metals, this obviating the change of wheels and resultant loss of time and waste of wheel in retruing.

The Churchill Machine Co. make an excellent turret grinder, one which is 36 in. × 16 in. in size with a maximum swing of 16 in. On this particular machine the greatest external diameter which can be ground, using a 12-in. wheel, is 12 in. There are eight work speeds altogether, four of them using the live spindle and four with the dead centre. The table also has eight speeds, it being possible to swivel the top table to an included angle of 9 degrees.

Where chuck work is being handled the tailstock can be removed, and the machine then operates purely as a chucking machine. Several attachments are provided with the machine, these including a four-jawed chuck, a face-plate, and a face chuck with draw-back collet.

This does not by any means exhaust the list of grinding machines, but enough has been said to show the trainee that the process of grinding has a very definite and useful place in modern workshop practice, and is, therefore, a branch of machine-tool work which he should get to know as thoroughly as lathe work.

THE SPARK TEST OF STEELS

A great advantage of this form of test is that it can be carried out on the steel at any point, e.g. as a billet, an ingot, a bar, a forging, or often a finished piece. The test is carried out on the steel as it stands, and the elaborate drilling of separate samples with the possibility of confusion is eliminated. At the present time, also, the test has great utility, because it enables pieces of undesired metal in a batch of different composition to be picked out quickly and cheaply, and set aside for scrap or salvage, whereas to have to analyse them chemically would constitute a prohibitive charge.

The principle on which the test is based is this. The effect of bringing a piece of steel into contact with the face or cutting edge of a grinding wheel is to force or wrench off tiny fragments of the steel. The wheel runs at a high speed, and the friction is so great that the temperature of these fragments is raised to such a height that they become white hot. This makes them brilliantly visible against a dark background, and their passage through the air as they are flung off has an almost comet-like trajectory, which is termed a " carrier line."

The basis of the test is that different metals give off sparks or particles of incandescent character each having a different trajectory and form. For example, wrought or ingot iron will give off a little bundle of individual lines called a " spark picture." A 0·2 per cent. carbon steel will give a line of brighter colour and will throw off a series of fine branches from this line known as " forks " or " primary bursts." These are due to the presence of carbon. It will thus be seen that wrought iron can readily be distinguished from carbon steel by means of the spark given off.

Raising the Temperature.—The effect of raising the temperature of a metallic particle to white heat and hurling it through the air at great velocity is to cause any carbon existing in the fragment to combine with oxygen in the atmosphere to form carbon dioxide. The change from solid carbon to gaseous carbon dioxide results in an increase of volume. This increase of volume is withstood to the best of its ability by the particle, and the result is the setting up of an internal stress that ultimately leads to the complete disruption of the particle, thus causing the fork or burst responsible for the branching out of the line. This, at all events, is the theory. The greater the percentage of carbon in the steel, the more marked is the branching effect, and this has proved fairly conclusively that carbon is the element causing these forks or bursts.

Examples.—A few examples will serve to illustrate these facts. Fig. 18 shows cast iron, which possesses a dull red, non-explosive spark that thickens towards the end. Fig. 19 shows wrought iron, whose spark is brighter, as indicated, and has a luminous extremity. If any traces of carbon are found in the iron, the extremity may reveal a burst or fork.

Fig. 20 shows mild steel. The thick, luminous iron spark is broken up by the branching due to carbon. Fig. 21 shows a 0·8 per cent. carbon-steel spark. The tendencies have virtually vanished, and the carbon branching occurs nearer to the grinding wheel. Fig. 22 shows a high-grade tool steel containing carbon. Fig. 23 is high-speed tool steel. An odd carbon spark or two are to be seen, but the rest are modified by the other alloying elements. The sparks are of an orange hue, and vary in brightness as they travel, giving the effect of an interrupted line, while they have a more luminous tip.

Fig. 24 is high-manganese steel. In this case the spark is different from that of the carbon spark inasmuch as the explosive particle leaves the luminous line at right-angles, and the sub-division of explosions is also at 90 degrees, as against the 40–50 degrees of the carbon sparks at Fig. 20. Fig. 25 is self-hardening Mushet

steel. Here an odd manganese spark is visible, and the relatively high tungsten percentage appears to give discontinuity to the spark. Finally, Fig. 26 is a tungsten magnet steel. Here can be perceived the respective sparks of manganese, tungsten, and the like.

Reverting to the effect of tool form on cutting power, it may be pointed out that as the side-cutting edge angle rises from 0 to 60 degrees the tangential force stays virtually constant at 395 lb. It diminishes a little for angles of 30 and 45 degrees. The longitudinal force falls away slowly from 173–90 lb., and the radial force increases from 48–180 lb. With an increase in the side rake angle from 0 to 48 degrees, the tangential force falls from 440–335 lb., the longitudinal force decreases from 245–98 lb., but the radial force keeps at practically the same force. An alteration in back rake angle from 0–16 degrees causes only a small diminution in tangential and longitudinal forces, but causes a fall in radial force from 75 lb. to zero.

With a variation in cutting speed for an otherwise stated cutting condition, all components of the cutting force stay virtually constant at the higher speeds. With the extremely low speeds, there is a variation in all values of components. The temperature between tool and work accurately measured by means of a thermocouple increases swiftly until a speed ranging from 10–20 ft. per minute is attained, governed by a number of variables, after which it rises in direct proportion to a speed increase.

The properties of a grinding wheel are governed by various factors, among which may be included (*a*) type of abrasive employed; (*b*) size or coarseness of the abrasive grains; (*c*) the method by which the wheel is bonded; (*d*) the degree or grade of hardness. There are a large number of different types of abrasives, many of them of proprietary manufacture, but for all practical purposes they can be divided into two main groups, the aluminium oxide and the silicon carbide.

There are about twenty different standard grain sizes or degrees of coarseness, all in everyday employment. The grain size of a grinding wheel is normally betokened by a number which signifies, roughly, the number of meshes per linear inch of a screen that will pass the grains. It is also feasible to combine two or more "straight" sizes, thus varying still further the degree of coarseness.

Methods of bonding the wheel include vitrifying, silicating, rubbering, resinoiding, and shellacing. The properties given by these different methods are capable of modification by alterations in the methods of mixing and moulding.

The vitrified and silicate wheels are manufactured in approximately 18 degrees of hardness. The majority of wheel-makers indicate these degrees by letters, employing the first letters of the alphabet for the softer kinds and the last letters for the harder kinds. Some makers reverse this procedure, and others again have their own private symbols. The remaining three types of bond are symbolised in no uniform manner, but are obtainable in approximately eight to ten different grades.

A further means of altering the grinding properties of a wheel is to regulate the structure or spacing of the grains of which it is composed. In this way it is possible to produce a denser or less dense wheel as may be desired for a specific job. Thus, the open structure is desirable for cylindrical grinding.

Choosing a Wheel.—In choosing a grinding wheel, there are a large number of considerations to be taken into account. In the first place, there is the actual metal to be ground, the quantity of metal to be ground off, the tolerances granted the type of finish desired, the arc of contact, and the kind of grinding plant available.

The influences of these considerations on the work itself can be importantly affected by additional considerations mainly controllable by the operator or his employers. These include the speed at which the wheel is run, the speed at which the work is caused to revolve, or the pressure if off-hand grinding is used, the state of the plant, and the operator's own skill. Tables 1 to 4 show the considerations and rules influencing the choice of the different ingredients of a grinding wheel.

One of the troubles most often experienced in the grinding of steel is checking or cracking of the material after the operation. This is usually due either to the method of heat treatment adopted or to some fault in grinding. If heat treatment is responsible, the cause is usually that the steel has been raised to too high a

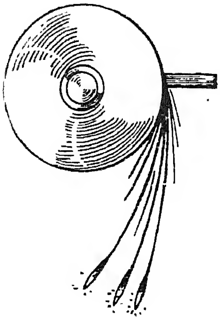


Fig. 18.—Cast iron.

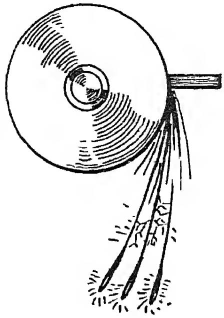


Fig. 19.—Wrought iron.

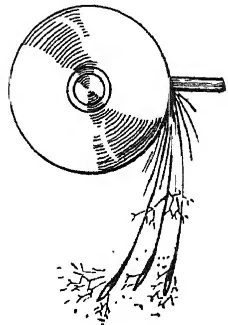


Fig. 20.—Mild steel

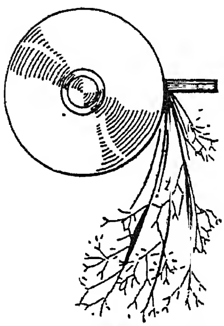


Fig. 21.—0·8 per cent. carbon steel.

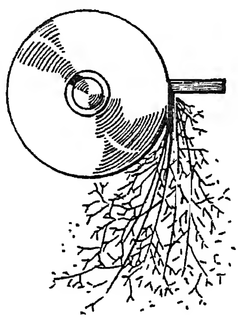


Fig. 22.—Tool steel.

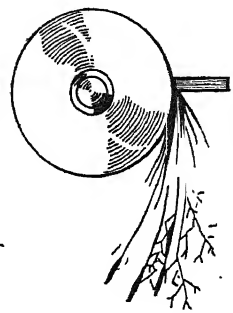


Fig. 23.—H.S. tool steel.

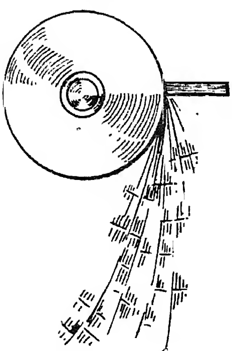


Fig. 24.—High-manganese steel.

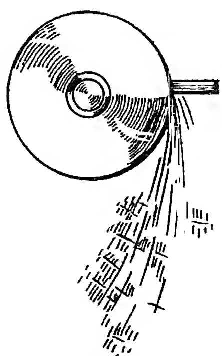


Fig. 25.—Self-hardening Mushet steel.

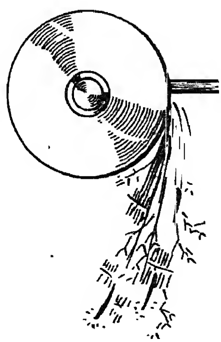


Fig. 26.—Tungsten magnet steel.

TABLE I

Physical characteristics of the materials to be ground

- Employ aluminium oxide grinding wheels for metals with high tensile strength
  - Carbon steels
  - Alloy steels
  - High-speed steels
  - Annealed malleable iron
  - Wrought iron
  - Tungsten
  - Tough bronzes
- Employ silicon-carbide wheels for metals with low tensile strength
  - Grey iron
  - Chilled iron
  - Brass. Bronze
  - Aluminium. Copper
  - Marble
  - Granite
  - Leather
  - Rubber
  - Pearl

TABLE II

Quantity of metal to be ground off
- Employ coarse wheels for speedy metal removal (except for very hard or tough steels, especially when surface grinding, when finer wheels may prove superior).

Required finish
- Use fine grain for fine finish.

Physical characteristics of metal to be ground
- Employ coarse grain for ductile metals and fine grain for hard, dense, and brittle metals.

TABLE III

Physical characteristics of metal to be ground
- Employ hard wheels on soft metals and soft wheels on hard metals.

Arc of contact
- Use harder wheels for shorter contacts, and vice versa.

Wheel and work speeds
- The higher the ratio of work speed to wheel speed the harder the wheel grade, and vice versa.

State of grinding machine
- Bad condition calls for harder wheels.

Skill of operator
- Skill means softer wheels and more economical production.
- Piecework normally calls for harder wheels than day work.

TABLE IV

Size of wheel
- Wheels over 42 in. in dia. generally made by silicate process.
- Wheels liable to bending stresses should be made by resinoid, shellac, or rubber process.
- Very thin abrasive saws should be made by resinoid, shellac, or rubber process.

Rate of cutting
- Employ vitrified wheels for quickest cutting at speeds below 6500 surface ft. per minute. Employ resinoid or rubber wheels at

Finish required
- Employ shellac or rubber wheels for best finish, where high speed of production is *less* important.
- Employ silicate wheels for cutlery.

temperature, the steel has been brought to temperature too rapidly, or it has been badly tempered.

Grinding Operation.—The trouble may be, however, and mostly is, traceable to the grinding operation. Often the cause is bad wheel selection, too hard a wheel having been selected, or the cut may have been too heavy, perhaps because an operator is trying to obtain output at a higher rate than is feasible. Sometimes, again, grinding may be carried on without adequate coolant, or the jet of coolant is not being correctly directed on the spot. The result of all these faults will be excessive heat generation at the points of contact, which cannot be dispersed quickly enough, and so causes the steel to overheat and crack as a result of the uneven expansion of the metal between different surface points.

The remedies for this trouble are mainly effected by the circumstances in which the work is being carried out. Thus the wheel can be less hard. The cut can be made less deep and the traverse of the wheel over the surface to be ground more quickly made. The provision of coolant at the point of contact may be made more plentiful, the wheel speed may be reduced, or the work caused to revolve or travel at higher speed. According to the type of machine employed, it may be feasible to prevent the checking of steel when ground by using thinner wheels, increasing the amount of coolant, or using wheels of finer grain.

Using fine-grained wheels has often overcome this trouble, but many makers now regularly recommend the use of a coarser, softer wheel as a remedy for local burning of the steel.

Surface Grinding.—It will be appreciated that if steel of hardened type is being surface ground in a machine having a vertical spindle, and the wheel is of cup type, the extent of the cut allowable will be restricted. The amount of feed is then entirely controlled by the power of the abrasive grains to pierce through the steel's surface. If the grains are coarse, i.e. of large dimensions, they will naturally be harder to drive into the steel than finer grains. In fact, they are able to penetrate only to a small percentage of the overall size of the grain, with the result that they do not tear out of the wheel face, and consequently blunt, fail to cut, slip over the work, and, if more sharply fed, cause immediate burning of the steel. On the other hand, when fine grains are used, the cut depth approaches more nearly to the grain size, which permit of their being torn from the wheel face before they have grown too blunt to do more cutting. Furthermore, in a wheel of fine-grained type, the number of grains to the square inch of cutting surface is much greater, so that the amount of metal ground off per unit of time is likewise greater.

Carborundum and Aloxite Brand grinding wheels are made to very close tolerances of grit size, bond structure, grading, and, consequently, performance. Standard wheels are free from uncertainty and guesswork. Given a definite grinding problem involving materials and machines of known characteristics, a wheel manufacturer can furnish a wheel accurately suited for the job.

Regarding grinding errors, work, machine, and wheel are the definite known quantities in the equation. Grinding troubles are usually due, therefore, to the variable unknowns, such as the condition of the grinding machine, skill of the operator in manipulating the wheel, and even to the operator's psychological reaction.

It is the unknown quantities which require expensive time-consuming experimentation. Often they are plainly visible to one who knows what to look for. But too often they are ignored, and a solution of a grinding problem is sought in a specially made wheel of special characteristics. Such a wheel will often produce a faultless grinding job even under the handicaps loaded upon it, but this special wheel will seldom do the job as efficiently as would a standard wheel operated under proper and usually easily attainable conditions. The grinding faults below will explain how many a grinding problem can be solved without recourse to specially made wheels.

Belts.—In all cases where belts are used, endless webbing or smooth-running spliced, laced, or sewn butted joints are recommended, in order to avoid chatter on the work.

Spindles.—High-speed grinder spindles of the ball-bearing type are very sensitive to slight irregularities. Because of their special construction and special races and balls, it is best that repairs be made only by the spindle manu-

facturer. Lubrication of spindles is of great importance. Use only the lubricants recommended by the spindle manufacturer.

Machine Play.—Since both wheel and work heads may be of the swivelling type, they must be checked for play and anchorage.

Belts.—Internal-grinder belts, with their high-speed short centres and small-diameter pulleys, must be frequently checked for oiliness, wear, and tightness, as slippage is an especially serious fault.

Dressing.—Faulty dressing is one of the most frequent causes of faulty grinding, short wheel life, and poor finishes. Keep careful watch to prevent wear in the diamond-holder bearings. Because of the small size of the wheels used in internal grinding, it is essential that the diamond be of proper size and maintained with a sharp point.

Wheel Characteristics.—Most internal wheels are less efficient than other wheels, because of the extreme change in wheel diameter with no corresponding change in spindle speed. Often it is possible to increase wheel life by using a wheel of greater width. Due to the limitations of chip clearance in internal grinding, it is necessary to use coarse, open wheels.

Tapers in Straight Holes.—Be sure the wheel head is parallel with the table traverse; use softer wheel or increase work speed for softer effect; correct work or wheel-head alignment; prevent gumminess of coolant; use lighter in-feed; be sure the wheel is dressed parallel to table travel; use harder wheel.

Bell-mouthing.—Reduce over-travel of wheel from hole.

Faulty Taper.—Be sure wheel is parallel to desired taper; eliminate backlash in headstock; harden or soften wheel as required.

Radial Break, Three or More Pieces.—Prevent excessive side strain.

Irregular Break.—Do not allow wheel to become jammed on work; prevent blows on wheel; do not use wheels that have been damaged in handling; examine wheel before using. Sound wheel by tapping.

General.—Do not use a wheel that is too tight on the arbor, as wheel will break when started. Prevent excessive hammering action of wheel. Familiarise yourself with the provisions of the safety code governing the use of grinding wheels—and observe the rules.

The Correct and Incorrect Application of the Diamond.—The important part played by the grinding wheel in model engineering practice makes it imperative that every detail, no matter how small, that will lead to greater output or better results, should receive consideration.

Centreless Grinding.—With a centreless grinding machine the work is ground whilst it is supported between a high-speed grinding wheel and a more slowly rotating control wheel, which is usually rubber faced. The support may be a plate or an equivalent member mounted in a block, and the control wheel slowly rotates the work by frictional contact against the abrasive action of the grinding wheel, which forces the work downward against the work rest and also against the control wheel. The latter gives a uniform rotation to the work, which has the same peripheral speed as the control wheel, the speed of which is adjustable.

The three methods of centreless grinding are: end-feed, through-feed, and in-feed. The through-feed method is applied to straight cylindrical parts, which are given an axial movement by the control wheel and passed between the grinding and control wheels from one side to the other. The in-feed method is used for parts which have shoulders or some part larger than the diameter to be ground, and the method somewhat resembles plunge-cut form-grinding on a centre type of grinder. In this method the length of the section being ground is limited by the width of the wheel, and as there is no axial feeding movement the control wheel is set with its axis approximately parallel to that of the grinding wheel.

The end-feed method is applied only to taper work, and the grinding wheel, control wheel, and work rest are set in a fixed relation to each other and the work is fed in from the front either manually or mechanically to a fixed end-stop. The grinding wheel or the regulating wheel or both are dressed to the proper taper.

In connection with taper work, if it is required to grind the work to tapered or other non-parallel forms, the grinding wheel, the control wheel, or both are acted upon by a diamond or other form of cutter to produce the required contour, involving the use of elaborate mechanism for bringing the cutter to bear on the wheel to be acted on.

The process consists of cutting the surface of the article with abrasives of progressively finer grain. In the final stages of the operation, the abrasives used make "scratches" in the surface which are imperceptible to the naked eye, and the article is then considered to be perfectly smooth.

To obtain the best results each "cut" should be taken as nearly as possible at right angles to the previous cut. For example, if a strip of metal is polished with 120-grit emery in a longitudinal direction, the next step would be to polish it with, say, 180-grit in a lateral direction. The reason for this is that if the cuts are made in the same direction, the cutting edges of the abrasives tend to run along the previous cuts instead of removing the crests of the microscopic ridges which lie between them.

The term abrasive generally conjures up a mental picture of a cutting agent which will remove metal or similar materials in a rapid manner and leave innumerable fine and very obvious cuts on the metal surface. Actually the term covers any granular cutting agent from the coarsest grade of emery to jewellers' rouge and similar materials. Some of the finer abrasives have a texture as fine as that of ordinary flour, and they produce scratches in the metal surface which are invisible to the naked eye.

Whatever the type of abrasive, it can be applied in one or more of four different fashions. These are:

(1) Grinding with wheels or discs consisting solely of the abrasive grains bonded together with a suitable cement.

(2) Grinding or polishing with felt bobs, mops, or tape on to which the abrasive is secured in a thin layer with glue or similar adhesive.

(3) Polishing with felt bobs, mops, fibre brushes, or tape to which the abrasive is applied whilst polishing. In this case a grease of some description is used as a bond or carrier, and the abrasive grains are held thereby in the form of blocks or sticks for convenient application.

(4) Sanding or polishing with felt bobs or mops to which the abrasive is applied in the loose state.

The first case is applicable to rough castings from which rough spots and protuberances must be removed. This may be termed the final stage of the fettling operation. The second instance covers the subsequent cutting-out and glazing operations, whilst the third is the method used for final polishing either before or after plating.

Loose abrasive is used only in special cases, such as sanding tubing with Trent sand or finishing off nickel or similar plating with a lime-finishing compound. Trent sand is damped with mineral oil to avoid excessive dust, as it is very fine. In the cases where lime finish is used dry it is applied in the form of lumps, although for most purposes this type of polishing agent is now bonded and applied in sticks.

Some of the principal abrasives used in polishing are emery, tripoli, lime, crocus, rouge, Trent sand, and chromium oxides, all of which have their own particular applications.

Sand-blasting.—Sand-blasting is a process which is much used in conjunction with polishing. Castings such as radiators may be sand-blasted prior to nickel-plating in order to remove small sharp irregularities, scale, etc., and to impart a regular granular appearance to the surface. Scale may be removed from most things by sand-blasting, and the improvement in the appearance of an old, badly rusted article has to be seen to be appreciated.

In a large number of cases nowadays the term sand-blasting is a misnomer, because sand has been largely superseded by steel shot, for ferrous metals in particular. Sand is used for items of jewellery, silver plate, and similar articles. Whatever the abrasive used, it is projected on to the article at a high velocity by a jet of compressed air, different air pressures and abrasive grain sizes giving correspondingly varying shades of surface.

Types of Polishing Wheels.—Polishing wheels are manufactured in a great

variety of types and sizes, ranging from large wheels of 36-in. diameter down to "fingers" and "nick" bobs a fraction of an inch in diameter or width.

Very large wheels are generally built up of wood laminations with metal retaining cheeks and centre boss, the periphery being covered with felt or leather. Wheels up to 24-in. diameter may be made of solid felt, canvas, or leather sections compressed together and mounted with metal cheeks. Below 12-in. diameter solid felt is considered the best material. A special type of wheel is made of fibre bristles mounted between wooden cheeks and, in conjunction with a fine grease-bonded emery compound, it is used for a final polishing operation prior to nickel-plating cast iron or similar material. A comparatively recent innovation in this connection is the introduction of cloth discs at intervals between the fibre bristles. A better finish is imparted to the work when using this improved brush, as the fabric sections hold the polishing compound and also serve to stiffen the wheel.

Walrus hide is frequently used for both solid wheels and leather-covered wooden wheels, the principal applications being emery bobbing and sanding. The hide of the walrus is obtainable in thicknesses ranging up to 1½ in., and as the grain possesses a coarse or open texture it forms an excellent key for the glue and emery. Various other grades and types of leather are also used for either single discs or laminated wheels.

Types of Mops.—Mops are available in numerous sizes up to about 14 in. in diameter. They are made of calico, cotton, sheepskin, chamois leather, and similar materials. The harder types are used, in conjunction with such compounds as tripoli, for polishing operations immediately prior to plating. Cotton and sheepskin are used for finishing nickel-plate, whilst chamois leather and extra-soft mops are used for rouging or colouring gold and silver. Mops consist of circular pieces of material placed side by side and stapled together at the centre, with a large leather or fibre washer at each side to take the heads of the staples and provide a satisfactory hold for the polishing spindle. The number of "folds" in a mop indicates the number of discs or circles of the material from which it is built up, and is consequently a guide to the width of the complete mop.

When a large-diameter mop has worn down to such a size that it is hard and unyielding, it is a good plan to remove the staples and split the mop into two or three sections. These sections may then be used as smaller mops if each one is stapled together again with a washer at each side. Ordinary nails may be used for staples and thin leather or fibre for the washers. Washers may also be saved from mops which have served their period of usefulness.

Band Polishing.—Emery tape is familiar to most engineers as a handy and economical substitute for emery cloth in cases where narrow strips are required. For polishing or grinding purposes the tape is made into the form of a belt or band and allowed to travel at a high velocity over two pulleys, at a suitable tension. A method of band polishing, which is well adapted to general work where a large variety of jobs must be catered for, consists of mounting one pulley on the ordinary polishing-lathe spindle. A special fixture carrying the second pulley is located at a suitable distance from the polishing lathe and incorporates a jockey pulley or other device for setting the band at the correct tension.

Alternatively, special machines are available which comprise a bed plate with the two pulleys attached. If desired, a metal rest may be mounted between the pulleys so that the inside or smooth face of the band will run over it. The band is supported in this manner to enable pressure to be applied to the article being polished.

If very heavy work is to be polished or ground, the usual practice is to use leather belts with cemented joints. These are dressed with the abrasive in the same manner as are the bands.

The band-polishing machine is becoming increasingly popular in engineering shops for use in the final dressing-off and finishing operations on various articles. It is particularly applicable to aircraft details where a high finish is required on innumerable small machined parts manufactured in duralumin, stainless steel, brass, and so on. Very often the machines for this class of work possess two pulleys arranged one above the other at about 18-in. centres, so that the band runs in a vertical plane. A small horizontal table provides a rest for the work and

facilitates the finishing of surfaces at 90 degrees. Dead-flat surfaces are ensured by the presence of a smooth, flat, metal support behind the band where the work is applied.

Dressing Wheels.—For several stages of grinding and polishing it is necessary to coat the wheels, mops, or bands with a layer of abrasive, usually emery or a similar cutting agent. The most-used adhesive for this is best Scotch glue, although for some jobs silicate of soda is favoured.

The tool to be dressed is first coated with glue and allowed to dry. A second coat of glue is then applied and the wheel is rolled firmly in a tray or trough of slightly warmed abrasive. When this is dry the wheel is ready for use for plain grinding.

It is desirable to warm the emery before use in order to obtain the full strength from the glue. If this is not done, the glue will be chilled and will lose an appreciable proportion of its adhesive power. Care in the dressing of wheels is amply repaid by results, as they give longer runs between dressings and retain their cutting power for a greater period.

If a glazing wheel is required, the surface of the abrasive is smoothed over with a pebble and treated with bobbing grease. This gives a finer cut than a plain wheel. Sometimes a mop is treated with abrasive, and when it is set hard the surface may be broken up by striking it with a hammer or by bumping the mop on a hard object. The result is a very flexible but fast-cutting tool, suitable for curved objects which might be difficult to polish with a firm felt bob. If carefully treated with bobbing grease when its cutting power is reduced due to wear, this type of mop will give surprisingly good service for glazing. The breaking-up of the surface is often carried out by running the mop on the spindle and pressing a piece of scrap metal or a stone on to it. The advantage of breaking it up in the manner previously described lies in the fact that none of the cutting power of the abrasive is wasted.

If a mop which has previously been dressed with a coarse grade of emery is to be dressed with a finer one, care must be exercised in cleaning the mop prior to doing this. The outer sections of fabric offer very little resistance to the pressure of the work, and in consequence the emery on these sections often retains its full cutting propensities when the centre of the wheel is worn out or is in a condition suitable for glazing. If the wheel is redressed or used for glazing, and this point is not attended to, trouble will be caused by the appearance on the work of cuts much deeper than is desired.

Scratch-brushing.—The process of scratch-brushing has several applications in connection with electroplating. The scratch-brush itself is a wheel built up of wire bristles, generally steel, brass, or nickel-silver, mounted between cheeks.

The wheel is used on a polishing spindle, and articles brought into contact with it receive a burnishing treatment, but no metal is removed. As a substitute for sand-blasting, large steel-wire wheels may be used for cleaning castings and imparting a uniform finish. These, however, are not true scratch-brushes.

A frosted appearance may be given to aluminium, brass, copper, tin, etc., by means of the scratch-brush. When the resulting surface is coated with a heavy bright lacquer, the result is very pleasing and is eminently suitable for ornamental purposes.

In the building-up of heavy deposits of metal, burnishing is necessary at certain intervals, and on some jobs the scratch-brush is used for this purpose. The object of this burnishing is to secure smooth, even, close-grained deposits; this is not always easy where these are required to be very heavy.

Scratch-brushing may be carried out as a dry process or with the aid of a scratch-brushing fluid. In some cases pumice powder is mixed with water and allowed to trickle on to the wheel. A guard round the spindle prevents the liquid from flying and also serves to collect it for further use.

Electro-tinning is often used instead of the old method of dipping, or hand-tipping, for items which are to be soldered. The subsequent soldering operation is greatly facilitated if the work is lightly scratch-brushed by the wet process after the tinning is carried out.

In addition to scratch-brushes, there are steel-wire wheels for power-brushing. They are of heavier construction than scratch-brushes, and can be used for a vast number of jobs. Among these we may mention cleaning castings, removing

the burr of frase from gears after machining the teeth, cleaning up welded and brazed joints, closing the pores in aluminium castings, removing paint and enamel from metal, decarbonising internal-combustion-engine parts, and so on. It will be seen from these that this type of wheel has a much more severe action on the job than has a scratch-brush.

A noteworthy feature of the steel-wire wheel is the built-up construction, which permits the replacement of worn sections. This is a sound idea from the point of view of economy, because on most jobs one part of the wheel wears more than another, and as this method of assembly permits the interchange of the sections, the wear may be made more even than would be the case with a one-piece construction.

Polishing Cast Iron.—It is not generally appreciated that there is usually a marked distinction between a surface which has been polished preparatory to plating and a surface which has been polished as a final operation.

A very high finish is required as a preliminary to plating because the high reflectivity of nickel and chromium (particularly the latter) causes a mark on the surface of the job to appear out of all proportion to its depth. For this reason it is difficult to obtain a really high-class finish on cast iron unless it is of a particularly good quality, possesses a close, fine grain, and is free from blow-holes. In commercial cast iron it is almost always possible to discern the grain of the base metal when the article is nickel- or chromium-plated, and very often dull patches are apparent where the grain of the metal varies slightly, due perhaps to chilling in the mould or some similar condition.

Large castings, such as stove tops or oven doors, are usually treated with about four grades of emery, 60, 90, 120, and 180 grit being probably the most popular. If the castings are smooth and clean, the first stage may be omitted. Sand-blasting makes it possible in some cases to omit the first two stages if the metal is of good quality. After polishing with the 180-grit emery the article may be glazed with a bob dressed with 180-grit and treated with bobbing grease. Good results are obtained if the grease is rubbed into the stationary wheel with the hand as a preliminary step. The final operation is carried out with a fibre wheel and a brushing emery compound.

Medium-quality work, which is to be polished only, may be treated with 60, 90, and 120 grit, the last operation being glazing with a 120-grit wheel and bobbing grease.

Polishing Steel.—It will be evident from the foregoing remarks on the polishing of cast iron that the processes involved are dependent on three things: (1) the condition of the surface at the commencement of operations; (2) the quality of the metal; (3) the class of finish required.

For the polishing of steel articles the processes are essentially the same as for cast iron, but as the original surface is invariably in a better condition for polishing, some of the first operations may be omitted. Thus, for plain polished steelwork, which has been drawn through dies (tubing or bar) or machined (bolts, etc.), a single polishing with a 120-grit glazing bob may be sufficient.

It is largely a matter of opinion as to what constitutes a satisfactory finish for a particular case, and the treatment of a polishing job at one place may vary considerably from the treatment of a similar job elsewhere. Operations may be added or left out to suit the individual requirements dictated by the standard of quality to be maintained. It must be emphasised that a higher finish is required on goods which are to be plated as distinct from goods which are to be just polished.

Polishing Brass.—As brass is a much softer metal than iron or steel it is a simpler matter to obtain a satisfactory finish on a brass article, although blow-holes in brass castings cannot, of course, be polished out unless they are only just on the surface.

For good-quality castings and machined parts in brass it is often sufficient to use 120-grit emery on a felt bob, and to follow this with a 180-grit glazing wheel. The final operation is mopping with a tripoli compound and a fairly hard cutting mop. Cases do arise, however, where the original surface is in a much less satisfactory condition. In this event more stages of cutting out with emery are introduced, starting with a coarser grade.

It is a generally accepted theory that the polishing mop, in addition to its

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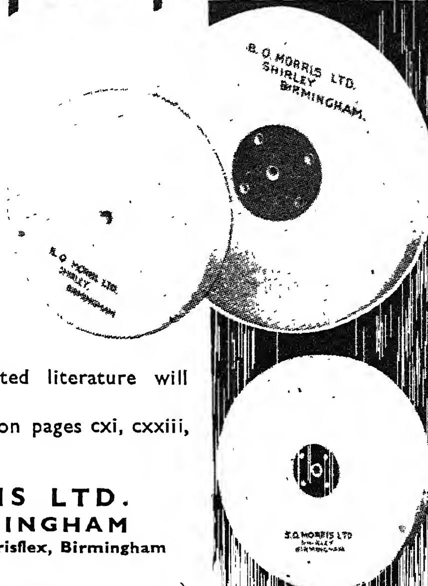

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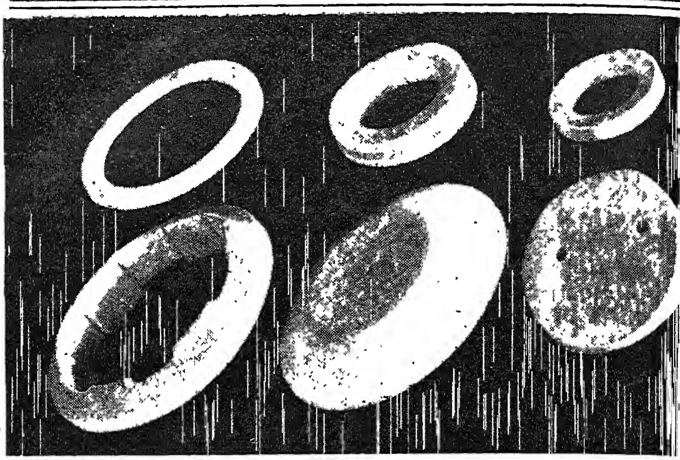

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cutting action on metal, also causes it to flow, and this is considered to be an important factor in the production of a high finish. Probably the best illustration of this flowing action under the mop occurs when polishing brass castings containing small blow-holes. After polishing, these holes will be found to have dragged and produced lines in the metal surface, commencing at the blow-holes and travelling in the direction of the mop.

An unusual finish for brass articles is obtained by lightly sand-blasting and polishing certain parts only, leaving the remainder with the sand-blasted surface. This is particularly effective when the article is nickel- or chromium-plated. Heating-installation globe valves may be treated in this manner, the flats of the hexagon base, and the valve bib and stem, being suitable parts for polishing for the relief effect.

For a first-class finish on brass which is to be lacquered, the polishing with tripoli may be followed by "colouring" with rouge or lime-finishing compound. A soft cotton or sheepskin mop is required for this job.

Grading of Emery.—Frequent reference has been made to 60-grit emery, 120-grit emery, and so on. In order to remove any doubts which may exist as to the exact meaning of these names, it may be stated that the "grit" of the abrasive used is a number which indicates the grain size. It is actually the linear measure or the meshing of the sieve through which the abrasive will pass. Thus 60-grit emery will pass through a sieve having 60 holes to the linear inch, or 3,600 holes to the square inch.

Barrelling.—Barrelling, or tumbling, is a process which plays an extremely important part in the manufacture of a multitude of small articles. It will be appreciated that the cost of polishing by hand vast numbers of small items like collar studs, screws, hooks, cable clips, pram-wheel hub caps, cycle spokes, washers, meat skewers, pencil clips, and so on would be exorbitant. Barrelling consists essentially of rotating a quantity of the work-pieces, together with a suitable polishing, scouring, or burnishing agent, in a container at such a speed that the mass tumbles over and over in a similar manner to concrete in a drum concrete mixer.

The actual process is not quite so simple as this, however. The shape and weight of the articles dictate the design of the barrel. A particular design eminently suitable to one job might give an unsatisfactory finish to another which is only slightly different. One rule which always applies is that the parts to be treated must not possess sharp edges or points.

Some articles are not adapted on their own to be barrel finished, but if a quantity of scrap metal of suitable size and shape is added to the charge satisfactory results can often be obtained. Rumbling stars are manufactured for the express purpose of inclusion with articles possessing recesses which would not otherwise receive treatment.

The abrasives used include emery, sharp sand, granite chippings, pumice powder, tripoli powder, coke dust, and so on. Mixed with oil, emery is very effective for removing scale from articles and for scouring the surface of rough parts. The other abrasives may be mixed with water for scouring purposes. Burnishing is achieved by the use of hard-steel balls possessing a highly polished surface. These, too, are generally used with water.

Polishing Lathes.—Polishing mops and wheels must be driven at a suitable speed to obtain the best results and effect the maximum economy of polishing materials. The machine used for this purpose is termed a polishing lathe. It is specially designed to suit the job in hand, the essentials being:

(1) The spindle must be located at a convenient height dependent upon whether underhand or overhand polishing is to be carried out.

(2) The spindle must be rigid and free from vibration at the high speeds often required.

(3) It must possess sufficient overhang to avoid fouling the headstock with large work-pieces.

(4) A convenient method of cutting off the motive-power supply to the spindle, in case of accidents or when changing the polishing tools, must be provided.

(5) In cases where the polishing tools need frequent changing, the method of mounting should facilitate this.

(6) The spindle speed must be suitable to the job in hand.

The first consideration is dictated by the type of work. For large castings where wheels up to 36 in. in diameter are used, overhand polishing is adopted. The top of the wheel rotates away from the operator and the work is applied to the top side. In this case the spindle is fairly low down near the floor.

Underhand polishing is carried out with smaller wheels mounted so that the underside rotates away from the operator and the work is applied on this face. The spindle in this case is, of course, higher than for overhand polishing.

Rigidity of the spindle is particularly necessary when using abrasive-covered felt bobs which are fairly heavy. If the spindle is subject to vibration, not only do the bobs tend to work loose in use, but the polishing is made difficult by the movement of the wheel.

For extra-large work (e.g. towel rails), polishing lathes with long snouts are available. The ends of the snouts carry additional bearings which provide support for the extra-long spindles.

Occasionally a heavy wheel will show signs of working loose on the spindle nose, or on a particularly awkward job some part may become involved with the wheel or spindle. In cases like these it is necessary to stop the spindle in as short a time as possible. If a wheel does come off a taper nose when travelling at 3,000 r.p.m., it can do considerable damage. For this reason care must be exercised when mounting hard felt bobs, scratch-brushes, and so on.

Methods of Mounting.—The quickest method of mounting a wheel on the spindle is by means of the taper nose just mentioned. In cases where considerable wear is likely, this nose piece is made short and detachable, to facilitate replacement. The taper end carries a thread which will screw into the hole in the centre of a polishing wheel and make its own thread inside the hole. (The hole in the wheel is plain when new.) For a double-ended spindle it is necessary to have a pair of detachable noses, i.e. one with left-hand threads and one with right-hand threads.

It is very dangerous to mount a bonded grinding wheel with a lead-centre bush on to a taper thread. The bursting action due to the taper may cause the wheel to break when in use. In addition to this, the wheel will not run true. All abrasive wheels of this type should be mounted between metal side plates and suitable friction washers.

In general, the polishing lathe with a self-contained motor is the most satisfactory. There is no belt to foul long jobs which are being polished, and the maintenance costs are reduced to a minimum. The motors used reach peak r.p.m. almost instantaneously and are easily brought to rest. In addition to these, the failure of a motor does not affect the remainder of the plant.

If, however, the conditions of the motive-power supply make a belt drive preferable to an independent one, there are several methods from which to choose.

Spindle Speed.—In order to obtain the most satisfactory results in the minimum of time and with the minimum expenditure of polishing materials, it is absolutely essential that the spindle be run at the correct speed. The main factors controlling this are the size and type of the wheel which is used. As the important point is to secure the correct surface speed for the wheel, the number of revolutions which it must make in one minute are dependent upon its diameter. In consequence, as a large wheel wears down it should be transferred to a faster-running spindle.

Good average peripheral speeds are 5,000 to 6,000 ft. per min. for abrasive dressed wheels and 6,000 to 9,000 ft. per min. for mops. For general work, using wheels of about 10-in. diameter, two spindle speeds of 3,000 and 4,000 r.p.m. will prove satisfactory for most jobs.

Dust Removal.—An unpleasant feature of metal grinding and polishing is the large amount of dust, fluff, compound, and so on which is thrown out from the wheel. It is compulsory to provide an efficient exhaust system to deal with this matter and thus safeguard the health of the operators.

The usual method is to fix a hood behind the wheel, of such shape that it does not interfere with the polishing process. (It is possible to arrange the top of the hood on hinges so that it may be swung out of the way when dealing with extra-large jobs.) The hood is connected to a main trunking by branch pipes, the exhausting being effected by a centrifugal fan at the extremity of the trunking.

The fan discharges into a dust extractor where the dust is separated from the air and may be collected for disposal. This method is applicable to large installations, but where only one or two lathes are required, it is possible to equip these with a small dust-exhausting plant situated near the machines.

Clamping Plates.—In small establishments a single polishing lathe is expected to perform a number of jobs, including grinding, using a bonded wheel. For this purpose spindles may be fitted with clamping plates. The spindle is threaded for a short distance past the taper thread so that a large nut may be screwed on, followed by the clamping plates and friction washers, preferably rubber (for use with bonded wheels), and finally another large nut for clamping purposes. When wheels which are fitted with metal bushes are used, the clamping plates are used without the rubber washers. Metal centre bushes do not screw on to a taper thread. It is important that the rubber washers be used on bonded wheels, as there is a danger of the wheel breaking under the clamping pressure if these are omitted.

Automatic Polishing.—Many repetition jobs are capable of being polished by means of automatic machines. In addition, strip material, rod, and tubing may also be treated in this manner. Individual items are generally held in suitable chucks which are rotated by small independent motors so that all faces of the work are presented to the mop. In some instances, three or four chucks are mounted on a head which is also capable of being rotated. In this way additional mops are brought into play in order to polish those parts of the job which are inaccessible to the first mop. The primary requisite of an article which is to be polished by means of automatic equipment is symmetry about its axis of rotation when fixed in the chuck on the machine. Suitable jobs are hub caps, reflectors, cycle hubs and rims, lamp-glass rims and meter bezels.

Rod and tubing may be satisfactorily polished by means of abrasive bands, the work being rotated and fed through the machine automatically. The now well-known principle of centreless grinding may be applied with advantage to automatic polishing machines for cylindrical work. The essentials of this principle are a large wheel rotating at high speed and a smaller wheel rotating at a relatively low speed. The larger wheel performs the cutting operation, the smaller one serving to rotate the work which will not "follow" the fast-running wheel.

A narrow blade supports the job and no further cutting takes place when the material is reduced to the required size.

Spindle Speeds.—The speed at which brushing wheels are revolved is an important matter. It should be remembered that wire wheels must always run more slowly than bristle or fibre wheels; also that the larger the wheel and the coarser the wire, the more slowly must it revolve. The following speeds are recommended for average working conditions:

Small bristle and fibre wheels	2,500 r.p.m.
Large bristle and fibre wheels	2,000 r.p.m.
Fine-wire scratch-wheels	1,600–1,700 r.p.m.
Medium-wire scratch-wheels	1,200–1,500 r.p.m.
Coarse-wire scratch-wheels	700–1,000 r.p.m.
Extra-heavy wire scratch-wheels	500–600 r.p.m.

To prevent wire brushes and wheels rusting when not in use, lay them in a basin of water in which a little lime has been added.

The guard is made from sheet metal, bent to shape and riveted. The baffle plate should be set at such an angle as to prevent the air from rushing through the slot for the wheel.

Electrolytic Polishing of Metals.—For some time now, even after degreasing, metals have been subjected to a chemical etch prior to plating to ensure an adequate key for the deposited metal. Latterly, a new application of the electrolytic process has been developed, namely, the electrolytic polishing of metals, in which, during the plating process, reactions take place at the cathode. The anodic oxidisation of aluminium and its alloys is a process which has been extensively used for both protection and decorative finishes on parts made of aluminium. The anodic process undoubtedly will be developed in the near future. In the process of polishing metal electrolytically, the metal part which is to be polished

forms the anode of the circuit, and the electrolyte consists of one or more acids, with the addition, sometimes, of chemical constituents to accelerate the polishing action.

Two methods have been employed. It has been used in the laboratory for the preparation of metallographic sections, and also for the polishing of metal surfaces. In industry the process is at present confined to some of the special steels, such as stainless steel, as well as to aluminium and nickel. It has been found that with these metals the new method competes favourably with the ordinary mechanical processes of buffing and polishing. In a typical arrangement for electro-polishing steel, a vessel containing the electrolyte is immersed in a cooling bath cooled by cracked ice, the cathode being an aluminium sheet surrounding the anodic specimen, which is centrally disposed. The part is degreased and descaled before it is placed in the electrolytic bath. An important factor in producing good results is the correct adjustment of the current density, for if this is too low the anode may be seriously attacked by the electrolyte, and result in heavy etching. If too high, pitting of the surface may occur. The time of treatment depends upon the fineness of the scratches on the surface of the part. The finer these are the less will be the time necessary to produce a polish on the surface. Agitation of the electrolyte is necessary, and this is usually effected either by moving the part or by stirring the solution. This avoids wave effect on the finish.

Not only is this process simpler than the mechanical, but it is more satisfactory from a metallurgical point of view; for example, in the mechanical method considerable heat, due to friction created by the polishing mop and the dressing, may cause distortion of the metal. Also, the heat may affect the softer constituents in alloys, whereas all constituents of the materials after electrolytic polishing are on the same macrographic level. Another factor is that with the electrolytic method the time of the polishing process is independent of the size of the specimen to be polished. In mechanical polishing, the time required increases with the size of the specimen.

The largest application of the new method is in connection with stainless steel. Two Amerian processes for this metal are based on electrolytes containing phosphoric and sulphuric acids respectively, and in both cases agents are added—phosphoric acid being employed with glycerine, while sulphuric acid is employed with an organic acid such as citric acid. Fairly high-current density is required to be employed in order to obtain good polishing results. Another solution which has been suggested contains sulphuric and hydrofluoric acid, but this would be objectionable owing to acid fumes.

The usual process for the anodic oxidisation of aluminium consists of cleaning, polishing, etching, anodic treatment in an alkaline and then in an acid solution, rinsing and drying, and the sealing of the oxide film by waxing. The articles are degreased in a trichlorethylene vapour degreaser. Where a diffused surface is required after polishing, it is immersed in a solution in hot water of caustic soda 2 parts and sodium fluoride 1 part (by weight). This new process of electrolytic finishing was used extensively in war production, and no doubt has found many new applications after the war.

METAL DEGREASING

The removal of grease is necessary as a preliminary to plating, cellulosing, or enamelling metal, or before repairing engines, components, and general machinery. It is required before pickling, sand-blasting, bright annealing, galvanising, and tinning raw materials and castings, and is necessary after metal has been subjected to cold rolling, drawing, pressing, machining, grinding, polishing, and similar processes.

In the majority of cases the finish and wearing qualities of the completed article largely depend on effective degreasing.

At one time certain types of work, intended for enamelling, were degreased by burning off the oil and dirt in a furnace; but this method is seldom employed

now unless the heating of the work can serve as a useful preliminary to a later process.

A further process which is seldom used nowadays is barrelling the parts in sawdust, following, in most cases, barrel polishing. Not only does this involve too much handling of the work, but it is apt to be inefficient when the parts have recesses or small openings.

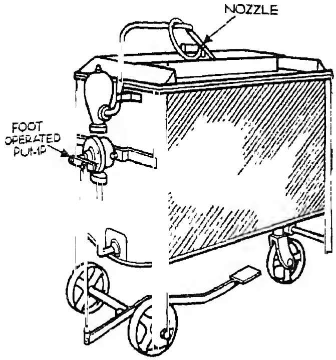

Fig. 1.—A paraffin degreasing tank provided with a foot-pump and spray, of a type employed in many workshops.

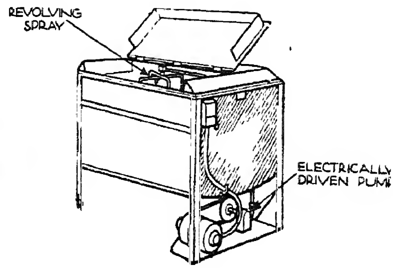

Fig. 2.—Another type of paraffin degreasing tank employing a rotating spray, pressure being generated by an electrically driven pump.

Washing in Alkaline Solution.—This is divided into three stages, the first comprising cleaning the parts in a strong caustic solution to remove the bulk of the grease or oil, the second consisting of exposing the work to the action of the milk alkali cleaner, and finally a thorough washing in water.

The alkali process can be used satisfactorily where batch or continuous working is required, and can be operated at a low cost, especially where spray-type equipment is used. A disadvantage is that where parts are treated in batches a certain amount of water and alkali finds its way on to the shop floor, while there is a possibility that the alkali may be trapped in seams or pockets of the component.

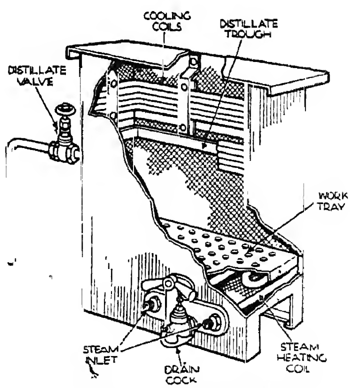

Fig. 3.—An I.C.I. vapour degreasing plant of a simple type.

Where subsequent liquid treatments are to follow, the alkali treatment is generally the most satisfactory. For cleansing parts prior to plating, the alkali degreasing process is generally combined as a stage in the automatic plating plant, and in some cases degreasing is effected electro-chemically in hot caustic alkali, followed by cold-water rinsing, an auxiliary cold-cyanide cleaning, and a cold-water rinse before the usual weak-acid dip, rinsing, and plating stages. The work is transferred to the degreasing, rinsing, and plating vats by an automatic conveyor.

The cleaning solution in the first vat is maintained at a temperature of 160° F. The solution is used electrolytically with a current density of 30 amperes per square foot. The work forms the cathode, and the hydrogen which is generated has a valuable cleaning or "scrubbing" effect. After a rinse in water the parts are transferred to a third vat containing a 5 per cent. solution of sodium cyanide, which removes any surface oxide; this is a cold rinse. Should any alkali still remain after the second cold-water rinse, it is neutralised in the next vat, which contains a weak solution of sulphuric acid.

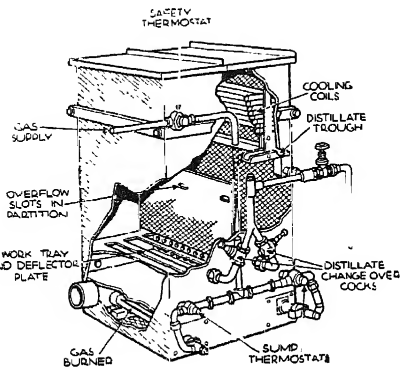

Fig. 4.—Liquor-vapour I.C.I. plant, in this case gas-heated.

Sand and Shot-blasting.—In the case of other components which are to receive different types of finish, sand-blasting or shot-blasting are the most widely used methods of cleaning away all traces of grease or foreign matter after normal degreasing. The advantage of abrasive blasting is that by controlling the type of abrasive and the pressure of the blast, the surface of the metal can be "keyed" in preparation for subsequent finishing.

When the work contains pockets, seams, and similar recesses which might trap an alkali degreasing liquid, recourse is generally made to degreasing by means of a solvent. A simple example of solvent degreasing, in which an inflammable solvent such as paraffin is employed, is the tank degreasing equipment where small quantities of parts can be cleansed by hand. In this case the paraffin is retained in the base of the cleansing tank, which is provided with a removable perforated inner bath or tray on which the parts rest. The paraffin is sprayed on to the parts by means of a short hose and nozzle, pressure being supplied by a foot-pump or by an electric motor. An alternative form, comprising a pump driven by an electric motor, is the enclosed tank, which is provided with a revolving multi-jet spray, rotated by the issue of paraffin under pressure.

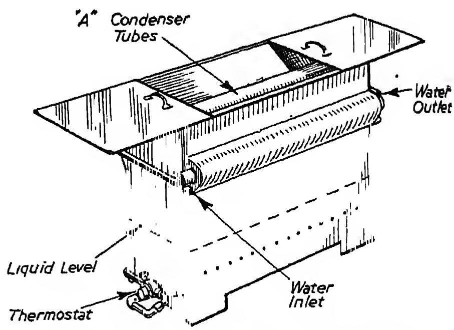

Fig. 5.—Trichlorethylene vapour cleaning tank.

Apart from the fire risk when paraffin or a more inflammable solvent is used, this type of degreasing apparatus is only suitable for dealing with comparatively small quantities of parts. When batches of parts must be dealt with in rapid succession, or when the plant is arranged for continuous operation, the trichlorethylene method is used. There are several types of trichlorethylene degreasing plant, including the well-known I.C.I., Froxy, and Epco plants. Trichlorethylene plants are further divided into three main types—the vapour, liquor-vapour, and multi-liquor types.

Vapour Baths.—The vapour plant consists of a tank in which a comparatively small quantity of solvent is boiled. The vapour rises until it reaches a bank of water-cooled condensing coils at the top of the tank; at this point it condenses, so that practically no vapour is lost, even when the tank is open. When the component to be degreased is suspended in the tank, the solvent condenses on it, dissolves the oil, and drips back into the sump. This type of plant is particularly well adapted to dealing with heavy articles, such as motor-vehicle engines. A complete engine can be degreased after removing such parts as the magneto, manifolds, timing cover, sump, and cylinder block. The engine is lowered into the vapour until it rests on the perforated tray. The lids are then closed as far as possible, and the condensed vapour will stream from the engine into the sump of the plant, carrying with it the oil.

The level of the vapour falls to some extent owing to the condensing action of the metal parts. When the parts attain the same temperature as the vapour, further condensation will of course cease, but by this time degreasing is generally complete. On opening the lids and raising the engine above vapour level it will dry immediately, although solvent trapped in any pockets must be emptied back into the plant sump. Components such as gearboxes can be degreased without dismantling, apart from removing the cover, while smaller articles can be lowered into the plant in baskets. A system of jets is sometimes incorporated in vapour plants in order to enable a stream of liquor to be directed on to particularly greasy components.

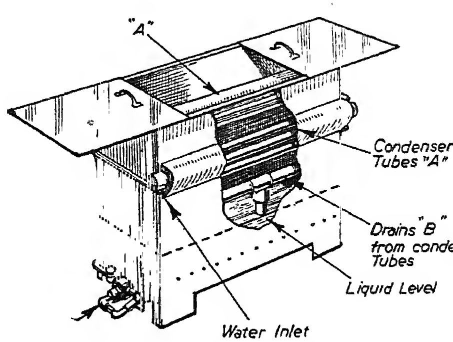

Fig. 6.—Showing the ducts down which the vapour drains.

Liquor-type Tanks.—If there are solid particles held in suspension in the grease, which may happen, for instance, in the case of work which has been grease-mopped after the use of a polishing compound before electroplating, the vapour plant will remove the grease but will leave the polishing compound or other solid adhering to the work. These items are best dealt with in a liquor or multi-liquor type of tank, the lower half of which is divided into two or more compartments containing boiling trichlorethylene. Escape of the vapour is prevented in the same manner as with a vapour plant by the provision of a bank of condensing coils. The article to be degreased is immersed in each compartment in succession, the last compartment containing pure solvent drained from the condensing coils. This type of plant also deals effectively with numbers of small flat parts adhering together through grease, which might not be dealt with effectively in a vapour plant.

Small parts, such as washers, nuts and bolts, and similar items, which would quickly reach the temperature of the vapour, thus stopping condensation before the whole of the grease has been washed away, can be dealt with effectively in a liquor-vapour plant. The parts are first degreased in boiling solvent, and then transferred to a vapour compartment, when any traces of grease from the contaminated solvent in the liquor compartment are removed. This type of plant is frequently used for degreasing and cleaning after polishing and before electroplating.

Vapour, liquor, or liquor-vapour plants can be designed to degrease the work as it passes along to the conveyor, or can form the first of several units on the conveyor line through which the work passes. I.C.I. continuous plants, for

instance, are to be found in the majority of large metal-working factories, heated by either gas, steam, hot water, electricity, heavy oil, or paraffin.

As will be seen from Figs. 5 and 6, the tank is constructed of metal and provision for reclaiming the vapour is made in the form of built-in condenser tubes "A" through which cold water is circulated, the trychlorethylene in the bottom is heated by gas, steam, or electric heaters (usually gas), and the vapour rises till it is checked by the cold zone caused by the condenser coils. The actual vapour may be seen as a greyish cloud inside the tank; being heavier than air, it will naturally not be lost by rising upwards.

The vapour making contact with the condenser pipes will turn to liquid again and drain down the ducts, shown "B" in Fig. 6, to the bottom of the tank to be revaporised, the liquid temperature being controlled by the action of two thermostats, one which opens up the gas supply as the liquid cools and the other which cuts off the gas supply should the temperature get excessive. This arrangement takes care of the operation, preventing loss by careless handling.

The parts to be cleaned are placed on a grille or tray in the vapour, and the time allowed varies with the size and condition of the work, small parts taking about five minutes whilst large or intricate parts will require up to fifteen minutes; on removal from the vapour no further attention is necessary and they will be found to be in the same condition as regards cleanliness as when first made.

Installation of Trichlorethylene Plant.—The plant should always be installed in a situation free from draughts, to prevent loss by evaporation and to minimise the possibility of inhaling the vapour. The water supply is connected up to the inlet of the condenser coils and the outlet piped to a drain; only a gentle stream is required, just enough to keep the coils cold.

Gas or steam are the most common heating agents, and when connected and the plant put into operation, a careful check should be made of the action of the thermostats. Care should be taken to see that when the liquid boils the thermostat cuts in and reduces the heat, at the same time not too much, as it would then reduce the heat to below boiling-point.

Much will depend on the make and type of the plant, and the makers' instructions should be followed closely. Cleaning out is, of course, necessary at varying intervals, dependent on the volume of work handled, and the procedure is usually as follows: The solvent is vaporised and, instead of being allowed to return, is drawn off through the drain usually provided near the condensers; it should be saved and put into a clean receptacle for reuse. The grease and dirt may then be removed; often the design of the plant will provide for the receiver tray and grille to be removed bodily. The interior of the tank may then be wiped out and the tray and grille replaced.

The original solvent is used again, plus a quantity of fresh liquid, sufficient to bring the total to approximately five gallons; of this, one gallon is almost always in a vaporised state and the remainder in the heating section. At the same time it is advisable to check the thermostat to see that it is not cutting in below boiling-point, thus ensuring that the maximum amount of vapour is obtained. The setting should not exceed 100° C. Always see that at least three to three and a half gallons of liquid remain in the tank during operation; and to assist in conserving the heat the folding or sliding lids should be kept shut except when putting work in or removing it.

Degreasing Powders.—In certain cases where the usual degreasing solution cannot be used, the so-called degreasing powders can be used. They are not particularly efficient, as they are merely scouring and abrasive mixtures which tend to scratch the surface. The mildest type of powder consists of fuller's earth, one part, kieselguhr (second grade), three parts, and soap powder, one part. Into this mixture absorb a grease solvent such as benzene or trichlorethylene in just sufficient quantity to render the powder slightly damp. The powder is kept in boxes with closely fitting lids to prevent evaporation.

A simple type of machinery-degreasing preparation consists of a hot 10 or 15 per cent. solution of trisodium phosphate. This forms a good emulsifying agent for grease, which it removes readily when swabbed over greasy parts. If the machinery is very greasy or the oil is caked on, the addition of about 2 per cent. of caustic soda will render the work easier.

To obtain a mirror-like finish, a high polish is essential on the surface of the work prior to the plating operation. Before any metal article can be plated with any degree of success it must be thoroughly and efficiently cleaned to remove every trace of grease or other foreign matter which may occur on the surface to be treated.

The subject of degreasing has been dealt with in the previous section.

Cleaning.—At one time caustic potash and caustic soda were in almost universal use for cleaning articles prior to plating, but nowadays specially prepared cleaners are available which are much more convenient to use and in many respects more efficient than either of these.

Some of these are used hot for a number of jobs, particularly where a considerable amount of grease is to be removed. Cold cleaning solutions are suitable for use after one of the degreasers already mentioned, but they do not give satisfactory results on greasy work. The cleaning process is greatly accelerated and increased in efficiency by using the solution as an electrolyte. When the work is made the cathode, and the tank side the anode (provided, of course, that an iron tank is used), the current may be said to cause a concentration of the cleaning agent around the work. In addition to this, a large quantity of gas is evolved and this has a marked mechanical effect in the loosening and breaking up of the dirt and grease.

As far as possible, nowadays degreasing is first followed by cleaning in a cold alkaline solution and then in a cold acid solution. In some instances the alkaline cleaning solution may be omitted. These methods are much quicker and cheaper than the older method of scouring with powdered pumice, or similar scouring agent. In small establishments and for special jobs, however, scouring still has its applications. The scouring is carried out by means of a hand-brush, which is dipped in water and then in the scouring agent. When the work is thoroughly scoured, water will adhere to it all over. If grease is present on the surface of an article, water will not form a continuous film on it.

In some cases, such as copper- and tin-plating, the cleaning chemicals may be incorporated in the plating solution in order to reduce the number of operations required. The surface of the job is automatically plated as soon as it is chemically clean.

Swilling.—The thorough and efficient swilling of every article which is being treated is an essential feature of successful electroplating. Many solutions can be ruined by the introduction of even a small quantity of a different electrolyte, particularly in the case of the delicately balanced plating solutions. In consequence of this it is absolutely essential that all trace of the chemical agent from one process be removed from the work by thorough swilling in clean cold water before it is introduced into the succeeding solution.

In order to maintain the necessary cleanliness of the water swill it is essential that the contents of the tank be renewed periodically. This is best ensured by allowing a gentle trickle of water to run from the supply cock. This action serves a double purpose. In addition to removing any salts which may have been introduced into the swill, in passing down the overflow pipe the waste water carries with it the film of dust and grease which tends to accumulate on the surface of the water in the tank. This is important, because this film of foreign matter is very likely to adhere to any article which is being removed from the swill since it must necessarily pass through the film last.

The efficiency of the process is greatly enhanced by agitating the water. A convenient and efficient method is to introduce compressed-air jets at the bottom of the tank. Pipes are laid on the bottom and are provided with a large number of small holes on their upper surface from which the air escapes, the resulting effect being similar to rapidly boiling water. Special precautions must be taken with the air supply to preclude the possibility of oil being carried into the water from the compressor.

A point which cannot be too heavily stressed is that work must be transferred from one vat to another with an absolute minimum of delay between the opera-

tions. It is fatal to the efficient completion of the process if the work is exposed to the air for a longer period than is necessary before the plating is completed.

Subsequent to the cleaning operation, brass articles are usually dipped in a solution of sodium or potassium cyanide to remove any lingering traces of oxide which may remain. This, of course, is followed by the usual swilling and acid dipping prior to immersion in the nickel vat, the purpose of the acid dip being to neutralise any remaining alkali which might upset the nickel solution.

Suspension of Articles.—As it is essential that no part of the work be touched by the hands once the cleaning operation is carried out, it is necessary to suspend the articles in the manner required for the actual plating process as a preliminary to cleaning.

Establishments which deal with general work consisting of innumerable sizes and shapes of articles are usually compelled to hang these on bare copper wire. The wire is available in coils, the gauges in common use varying from 18 s.w.g. to 24 s.w.g. It is usually possible to decide on two or three standard lengths into which the wire may be cut with a minimum of waste.

Wire Economy.—It is not convenient to use wire a second time for nickel-plating because the nickel coating cracks and peels off when the wire is bent. Wire which has been used for chromium-plating, however, may be used in the nickel process. If the chromium deposit is removed from the wire by immersion in hydrochloric acid, better contact is maintained with the work. Whilst this is not essential, it is to be recommended because chromium offers a very high resistance to electrical contact. Wire is a fairly expensive item and the little trouble involved in economy measures is well repaid.

When small screws are suspended on wire the latter should be twisted round the screw so that it lies in the thread. If two turns round are taken in this manner the screw is then twisted, a secure fastening is obtained and the screws will not be lost in the vat, a not uncommon occurrence with small articles.

As far as possible, all articles should be suspended from some point which is not required to be plated, e.g. by screwing suspension screws into tapped holes, using spring clips in the interior of the article, making connection to some protrusion on the back of the article and so on.

Insufficient care in the suspension of articles can result in considerable trouble. If the electrical contact is faulty in the electrolytic cleaners the article is improperly cleaned and strips may result; that is, the deposit may strip from the base metal because of imperfect adhesion. The same fault in the nickel solution may cause either strips or thin patches in the deposits in the vicinity of the wire. Many troubles can, in fact, be traced to faulty connections in the electrical circuit. For this reason all bars and connections on the vats should be kept perfectly clean in order to ensure a satisfactory path for the heavy currents involved. Faulty connections soon become evident, if they are outside the solution, due to the heat generated.

When a job is being wired up, its surface area must be considered as well as its weight. If this is not done the suspension wire may be overloaded in the electrical sense, and it will become red hot and break, most probably in one of the cleaning vats. There is always a temptation to select a wire which will support the weight of the job, rather than one which will carry the necessary current, particularly if the article being plated is made of thin sheet or tube.

Hollow articles should be suspended so that " pockets " are not formed which would be instrumental in transferring solution from one vat to another. In addition, pockets liable to fill with gas, and so prevent contact of the solutions with portions of the work, should also be avoided.

Cathode Suspenders.—Suspending articles by means of wire is fairly expensive for four reasons, which are as follows:

1. The wire is scrap after use.
2. An appreciable length of time is required to attach the article to the wires.
3. A similar, and sometimes longer, period is required to remove the articles from the wires on the completion of the process.
4. The transference of a large number of wires from one vat to another is not by any means a rapid and convenient operation.

In order to overcome these difficulties, cathode suspenders or racks have been developed. Basically, a cathode suspender consists of one or two rods with small

hooks or clips positioned at intervals along the length. The top end of the suspender is fashioned into a hook which fits on the vat cathode bar. In use, the articles to be plated are simply attached to the suspension points and the whole of the suspender and its load can be transferred from one vat to another with a minimum of effort.

One objection to the use of these racks is the manner in which the nickel deposit accumulates on them. Due to the gradual increase in area, there is a progressively increasing waste of electric current and metal from the vats. An ingenious type of rack has been devised which not only overcomes this trouble, but can be adapted to a variety of articles by changing over the detachable suspension sprays or hooks. The stem of the rack is covered with an insulating medium which does not become coated with the metal deposit, and in consequence of this appreciable economies are effected in current and metal. In cases where the articles are fairly light and remain on the suspension hooks by their own weight, care must be exercised when a loaded rack is being immersed in a solution or the work will be washed off the hooks. This can also take place in a solution which is agitated by means of compressed air or where the bars of the vat are subjected to a continuous movement as in some plating operations.

Spring Connectors.—It is always preferable to use spring connectors where possible as these give a better contact and there is less chance of the work being lost at the bottom of the vat. Some jobs may be suspended by means of special hooks which may be screwed to suit threads already existing on the work-pieces. This at first glance would appear to be an almost foolproof arrangement, but in practice it often occurs that when the screw is tight the hook is pointing in the wrong direction for the job to hang correctly in the vat. The screw must then be slackened off to obtain the correct position and a doubtful contact inevitably results. It is possible to effect a considerable improvement on many jobs by fitting springs at suitable points on the hooks. The springs are not intended to carry any current but they ensure a reasonably efficient contact across the threads. It should be noted that ferrous metals are unsuitable for racks, as they offer a fairly high resistance to the current flow and give poor contact on the vat bars.

Sometimes a plater is called upon to deposit metal on a light chain such as may be used on chandeliers. It often happens that difficulty is experienced in getting the chain to plate over the full length, because of the cumulative voltage drop over the large number of contact points which exist between the links. A successful method of overcoming this difficulty is to suspend a weight at the bottom end of the chain—by means of a non-conductor between them so that the weight does not absorb any current. If a wire is led to the lower end of the chain, the voltage drop is reduced by a half and the weight ensures a good contact between the links. Rubber bands, cut from pedal cycle inner tubes, make excellent non-conducting links to place between the weight and the chain end.

Reconditioning often involves plating parts which are loosely assembled and cannot be taken apart. Either the use of weights or wiring to all parts of an assembly can be relied upon to compensate for the faulty contacts which usually exist across the joints.

Economies in electric current and anodes may be effected in many cases by slinging or racking the work back to back wherever this is permissible. Plates or flanges which are to be screwed on to a wall, for example, need not be plated on the back side, and the all-round saving is considerable. Care should be taken, however, to see that no dirt or grease likely to pollute the plating solution is left between the two articles.

NICKEL-PLATING

The process of nickel-plating consists essentially of passing an electric current through a solution of nickel salts in water, by using the work as the cathode, and sheets or rods of nickel as the anode. The metallic constituent of the solution partially dissociates from the non-metallic, and the electric potential between the electrodes causes it to "migrate" towards the work, on which it is then deposited. The remaining part of the solution combines with the nickel anode to replace the metal which has been removed.

The splitting-up of the solution in this way is termed ionic dissociation and, as the metal ions deposit on the cathode, they are more exactly described as cathions. Similarly the ions which migrate towards the anode are termed anions.

The amount of metal deposited is related to the amount of current which passes through the solution and, subject to certain qualifications, this is approximately proportional to the difference of potential between the vat terminals when considered over a given period.

Contact Resistance.—In consequence of this it is a common practice to use the voltage across the vat terminals as a guide to the current density, since no calculation for area is required, and it is here that the necessity for perfectly clean contacts becomes evident. A faulty contact results in an increase in the resistance to the current flow and if only one or two articles are affected in a vat load, no indication will be evident on the voltmeter and the deposit on these articles will suffer accordingly. The ideal method of control is to compute the approximate area of the work, multiply this by a specified current density per unit area, and adjust the current flowing through the vat so that the ammeter reading agrees with this figure.

The process of nickel-plating is carried out in lead-lined wooden vats which nowadays are fitted with a number of appliances for increasing the rate of deposition and improving the quality of the nickel deposit. The lead lining is protected by a second lining of wood which prevents accidental short-circuiting of the current through contact of the work with vat sides, and so on.

Rapid Deposition.—In order to obtain the maximum output from the plating vats it is now a common practice to use heated and agitated solutions, as by this means it is possible to deposit metal approximately three times as quickly as with a cold, still solution. A further advantage of agitation is that the minute hydrogen gas bubbles, which sometimes form on the work and cause pitting, are freed and rise to the surface of the solution. Its chief object, however, is to ensure that the whole of the solution is maintained in a uniform condition and is not unduly depleted of metal in the vicinity of the work by the extra-high current density made possible by raising the solution temperature.

Air Agitation.—The most efficient and economical method of agitating a plating solution is by means of compressed air. This is passed into coils made of lead piping which lies on the bottom of the vat. The upper surface of each coil is provided with a large number of small holes from which the air escapes and so passes through the solution, giving an effect of continuous ebullition.

It is absolutely essential that the air be perfectly clean and free from oil, dust or other foreign matter. If the supply is to be drawn from a compressed-air main which feeds other plant, washing and purifying apparatus must be installed to ensure a supply which fulfils these conditions.

The best plan is to have a special pumping plant for the plating vats, as the compressors used are designed for the purpose and less contamination of the air is likely.

Filtering.—Filtering of the solution can also be effected by means of the compressed-air supply working on the ejector principle. It is inevitable that a certain amount of foreign matter should find its way into the vat and this, together with any anode sludge which forms, must be removed by filtering. If this is not done, minute particles of the foreign matter will settle on the work and a rough finish will result. It should be noted that this is particularly applicable to agitated solutions, as the agitation keeps the foreign matter in suspension, whereas with a still solution it settles as a sludge on the bottom of the vat.

The filter pump consists of a coil of lead pipe about 1½-in. diam. lying on the bottom of the vat (alongside the agitation coils) and provided with a large number of holes along its length. The pipe is bent at right angles so that it protrudes above the surface of the solution and here it is bent through 180 degs. in a short radius to form an outlet into the filter bag. The air inlet is a smaller-diameter pipe passing into the larger at the top and continuing to a point well below the normal solution level, where it is bent back on itself to form a jet pointing upward.

The jet of compressed air which is delivered from this point imparts energy to the solution in the upright part of the filter coil, and causes it to rise to the outlet whence it passes into the filter bag. The filtered solution returns to the vat and the filter bag is washed out from time to time to remove the sludge which it

collects. It is a good plan to pass through a filter all liquids which are to be added to the solution.

For some jobs it is desirable to have a portable apparatus and this is now available as a self-contained electrically driven pump unit, mounted on a trolley together with the filter.

Losing an article in the solution is not by any means an uncommon occurrence, and as no foreign bodies can safely be left in the bath, it is necessary to have a long pair of tongs and a hook conveniently to hand for the recovery of any item which might fall to the bottom of the vat. To neglect this point is to court trouble, since many base metals are capable of contaminating the plating solutions and upsetting the delicate balance which is essential to efficient working.

Ensuring Uniform Deposition.—It is not always possible to obtain a uniform deposit on every article in a vat load, since it is almost inevitable that some of the articles will be in closer proximity to the anodes than others, and will consequently receive a somewhat heavier deposit.

The most convenient method of overcoming this difficulty is to move the work about in the vat, instead of allowing it to hang in one position relative to the anodes. This may be effected in two ways. The first is oscillation of the cathode rods by means of a toothed quadrant engaging with teeth on the rods, and moved through an arc by a slow-running, electrically driven crank.

The second method is more elaborate and has other advantages. In this, the cathode suspenders run on an oval track, and the work, once inserted, completes at least one circuit of the vat whilst being plated. The speed of the work can be adjusted so that the required amount of metal is deposited during one circuit. In consequence of this the vat may be loaded and unloaded at the same point. The process comes under the heading of semi-automatic, and identical conditions of plating are ensured for each article.

Throwing.—Due to the resistance of the solution increasing as the anode-cathode distance increases, the amount of metal deposited on a part of the work remote from the anode is considerably less than the amount deposited on a portion which is much nearer. As the resistance of the solution is proportional to the distance just mentioned, it is evident that the greater this distance, the less the discrepancy between the current densities on remote and adjacent parts of the work. Thus, if the nearest part of the job is 6 in. from the anode, and the farthest part is 12 in. from the anode, the distance to the latter is twice that to the former.

If the work is moved so that the nearest part is 12 in. from the anode, the farthest part will be 18 in. distant and the ratio will be 2 : 3 instead of the previous ratio of 1 : 2.

It is evident from this that on very irregular jobs an increased anode-cathode distance may often be used to advantage. Some solutions will not deposit satisfactorily in deep recesses in the work, and they are said to be deficient in "throwing" power. By suspending the work at a greater distance from the anodes in the manner just described, this fault can be mitigated to some extent.

Anodes.—Because of the necessity for preventing the introduction of even small quantities of foreign materials into the plating solutions, it is necessary to use anodes made from nickel of a very high degree of purity. The metal used for this purpose nowadays is 99–100 per cent. pure, and anodes are produced from it in three different forms—cast, rolled, and depolarised—the latter being noteworthy for their remarkably uniform wear. Cast-nickel anodes corrode badly as a rule, and it is usually desirable to keep them covered with specially made bags to prevent the anode sludge, which is often very gritty, becoming partially suspended in the solution and causing a rough surface on the work.

There is an appreciable amount of scrap from cast anodes because they become very spongy in use and tend to crumble away to some extent. In addition to this, the end which must be discarded when the anode has served its period of usefulness will very often weigh several pounds.

The use of the depolarised anodes previously mentioned effects a considerable reduction in the quantity of this scrap. This is an important point, since anodes are expensive as a result of the necessity for using the purest metal obtainable. To some extent this economy is due to the shape now adopted for the anodes. The present practice is to make them of an oval cross section, whereas the older type were made in the form of flat plates with a much larger cross-sectional area.

It often happens that anodes become covered with a coating of oxide or similar substance which in some cases is insoluble and resists the passage of the current. To cater for this, anodes should be scoured periodically if efficient working of the bath is to be maintained.

Automatic Plating.—Modern methods of mass production have created a demand for automatic plating plants. The general principle involved is the transference of the work from one vat to another by means of chains. Actually, the work is loaded on to the chain-conveyor at one end of the plant, and after each process is transferred to the next vat by transfer chains, which are synchronised with the conveyor chains. As the work must travel the full length of each vat and the speed of the conveyor is constant throughout, it is evident that the length of each process is proportional to the length of the vat in which it is carried out.

In consequence of this it is necessary to design automatic plants to suit the job in hand.

Drying Out.—When plated articles are removed from the plating bath they should be swilled in clean water and then "dried out." This is achieved in two or three ways, the preliminary in most cases being a swill in hot water. This can be followed by covering the work in sawdust which is contained in a bin having a false bottom containing hot water. Boxwood sawdust is used for small parts, but ordinary sawdust will serve for many jobs, provided that it does not contain too much resinous matter. An alternative method is to hang the work in a drying oven, or in a stream of hot air, after immersion in the hot water.

A Protective Film.—If desired, whale-oil soap may be added to the hot water. This leaves a thin protective film on the work which is particularly useful when drying out sand-blasted cast iron. It has been established that nickel deposits on rough surfaces are more porous than those on relatively smooth surfaces, and if this porosity is such that corrosion of the base metal occurs, some protective film is very desirable. The work should be thoroughly swilled before it is introduced into the hot-water tank, since the presence of nickel salts or weak acids in the water greatly increases the possibility of rust occurring on nickel-plated ferrous metals which have a rough surface similar to that possessed by unpolished castings. The addition of a small quantity of ordinary washing soda to the hot water will invariably prevent this trouble from occurring. This "wrinkle," incidentally, is useful to the toolsmith when quenching tools in water after tempering.

If the base metal is excessively porous, the pores become charged with the chemicals used in the various processes, and if not efficiently swilled out these chemicals will cause "spotting out" on the plated surface. The alternate use of hot and cold swills after plating helps to prevent this trouble by expanding and contracting the pores and so "squeezing out" the contents.

CHROMIUM-PLATING

The metal chromium is remarkable for its intense hardness and resistance to wear when it is deposited electrolytically on to a base metal. One of its properties is its resistance to corrosion and tarnishing, but in order to make the best use of this it is necessary to deposit the chromium film on a preliminary coat of nickel.

The principal reason for this is that the chromium deposit is extremely thin (approximately 0·00002 in., or $\frac{1}{50000}$ in.), and is consequently somewhat porous. This porosity permits the ingress of moisture to the junction between the base metal and the chrome deposit, and corrosion results, assisted very often by "battery action" between the two metals.

A good-quality nickel deposit of about 0·0008-in. thickness provides a protection against this defect since it is not porous and is practically inert at the nickel-chrome junction. If the chromium is deposited straight on to the base metal it invariably cracks and peels off after a relatively short time. On the other hand, there is little advantage in giving the base metal a preliminary nickel deposit if the nickel is not of a good quality, and is in itself porous. It is unfortunate that a large percentage of commercial work suffers from this defect,

which makes itself apparent by a film of rust or oxide forming on the surface of the chromium plating.

In the preliminary stages this can generally be removed quite easily, but after a time the whole surface becomes rough and pitted, and cannot be polished. When this occurs, the chromium plating is generally thought to be defective, but the foregoing makes it apparent that in reality the nickel deposit is responsible. Hence a tough, non-porous, thick and adherent deposit of nickel is essential if the work is to retain its finish indefinitely.

On no account should ordinary metal polishes be used for polishing chromium plate, as their abrasive nature has a deleterious effect on the deposit. A good-quality plate requires nothing more than a wipe with a damp cloth or wash-leather to remove dust, mud or similar substances.

The Chrome Vat.—Chromium-plating vats are best made of thick welded iron or mild-steel plate. This should have a thick lead lining protected with heavy reinforced glass sides. Wood is quite useless in positions where it is likely to come into contact with any appreciable quantity of the chromic-acid solution, as it rapidly deteriorates under the action of the latter. For this reason it is desirable to cover all duckboards, floorboards, and so on, around the vat, with lead sheet to protect them from the acid. The solution must be heated, and as it is undesirable to have heating coils submerged in the acid, the most satisfactory method of achieving this is to arrange a water-jacket around the outside of the vat. Water in this jacket may be heated by the usual means, or if desired the water-jacket may be omitted and suitable external resistance coils can be fitted to provide for electrical heating.

During the operation of the vat, large volumes of gas are evolved, and in passing through the solution this gas causes a spray of acid to rise from the surface of the liquid. This spray must be efficiently removed by an exhaust system, as it is very unpleasant, and even dangerous, to work in an atmosphere charged with it. To achieve this end it is necessary to fit exhaust ducts having slots along the top of the vat and terminating in a condenser box at one end. A duct leads from the top of this box to the exhaust fan and thence to the open air. After running for some time the condenser box will be found to contain a quantity of solution. This should not on any account be returned to the vat as it contains a very large percentage of foreign matter which is drawn into the system from the air.

The vat should be supported on a strong floor, preferably on brick piers or rolled-steel joists, in order to provide an air space below it. Neglect of this point often leads to corrosion of the bottom of the vat.

Anodes.—Unlike most plating operations, chromium plating does not involve the use of anodes of the same metal as that being deposited. The two principal reasons for this are that chromium anodes would add metal to the solution faster than the work would remove it, and in consequence the density of the solution would gradually increase. The second reason is that chromium in the pure state is difficult to obtain in any large quantity. In consequence, it has been found desirable to use anodes of lead. A corrugated section has been adopted to give greater area and increased mechanical strength as compared with the original flat-strip type.

Suspension of Articles.—Owing to the exceptionally high current densities used for chromium-plating (often as much as ten times the current for nickel-plating), great care is necessary in the suspension of the work in order to ensure satisfactory results. Chromium-plating is by no means as easy as nickel-plating, but many of the difficulties which arise are due to mechanical factors affecting the current supply to the work, the method of suspension, and the disposition of the articles in the vat.

As far as possible the area of the work should be estimated, and if wires are to be used for suspension purposes the number and thickness of these may be easily arrived at if the carrying capacities of the sizes in use are observed. Owing to the amount of air drawn into the vat by the exhaust system, high current densities are permissible in the suspension wires because of the cooling effect of the air. Thus a wire in the vat will easily carry a current which would raise it to red heat in still air. Some power loss is attendant upon this, of course, as a slightly higher voltage is necessary to operate the vat, but where power is cheap the overall economy on the wire saved will generally offset this by an appreciable amount.

The use of the voltmeter alone as a guide to the current being applied to the work is not to be recommended. Much more uniform results can be achieved by estimating the area of the work and calculating the average required. If an exceptionally high voltage is necessary to obtain this amperage then it will be evident that a connection is at fault and is offering a resistance to the current flow.

Where the type of work permits, specially constructed suspenders with stout spring clips or screw attachments are to be preferred. It must be stressed that perfect contact must be maintained between the article and the suspender. If any resistance occurs at the contact point there is a drop in the voltage across the connection and the article will not receive any deposit in the vicinity of this point. The resistance can be such, in fact, that the article will not plate at all. This, of course, applies equally to wires and suspenders.

One of the most frequent causes of this trouble occurring in the case of suspenders is the neglect to strip the chromium from them at frequent intervals. This is necessary because chromium has a high inherent resistance. Because of this the use of wire a second time for chrome-plating is not advisable unless the chrome deposit is stripped off it. A brief immersion in hydrochloric acid will effect this, but the wire must be thoroughly swilled afterwards.

Motor-car radiator shells form an example of another difficulty which has to be met. In this case the area of the job is considerable, but as the metal is extremely thin it possesses an appreciable resistance and makes even current-distribution difficult. To counteract this, several contacts should be made at suitable points between the work and the suspension hooks, which should extend almost to the lowest extremity of the shell.

The best metal to use for all suspension hooks, racks, and so on is copper. Brass is not to be recommended, as it deteriorates very rapidly in the solution and the presence of any quantity in the latter is not likely to improve it. All joints in the suspenders should be screwed, welded, or soldered. If spring clips are to be used they may conveniently be made from hard phosphor-bronze strip which is available in coils. This should be attached to the centre members of the suspenders by screws, as heating destroys its springy properties.

The recommendations for the suspension of articles which were made in the section on nickel-plating are even more applicable in the case of chromium-plating, where slight drops in the voltage and current often have a pronounced effect on the quality of the work.

Any work-piece which is accidentally lost in the vat should be recovered immediately, as the acid is extremely powerful in its corrosive action, and even a brief spell of immersion will ruin most things. Apart from this the introduction of foreign materials into the solution is to be avoided.

The deposit on prominent parts and pointed extremities of the work is often "burnt," and has to be polished after the plating operation. (The bright chromium-plating process produces work which normally does not require subsequent polishing.) This difficulty may be overcome to a great extent by one or more of three methods. In the first case insulating shields, preferably glass, may be hung between the anodes and the part in question. The second method makes use of the inherent resistance of the metal from which the article is made. This is achieved by connecting the hooks or wires to those portions which are most difficult to plate, and so compelling the current to pass through the work to the more prominent parts. The old-style cast-iron fireside trivet affords a good example of this method. Normally these trivets are somewhat difficult to chrome owing to the high resistance of the elaborate pattern cast into them. The usual result is a burnt outside edge and a nickel centre. If connections are made to several points in the pattern, well away from the outside boundary which has a relatively heavy section, little difficulty should be experienced in obtaining a satisfactory result.

Special Anodes.—Auxiliary anodes are used in some cases where the hollows in the work are very deep and the deposit will not throw into them. (The throwing power of chromium solutions is always comparatively poor.) The type of anode generally recommended for this work is a lead tube of such dimensions as may be necessary to ensure a reasonable clearance all round between it and the article. This sometimes necessitates the fabrication of an anode which might

never be used again, and a better plan for a number of occasions is to have a suitable length of narrow lead strip (say $\frac{3}{16}$ in. wide and $\frac{1}{8}$ in. thick) permanently attached at one end to the flexible cable by which connection must be made to the anode rod. This strip may easily be formed by the fingers into any desired spiral form of the right shape and dimensions to suit the job in hand. If the hollow is very deep the current should be made to pass to the lower end of the spiral first, by winding the latter with a straight " leg " down the centre. Scrap pieces of anode melted down and run into a groove in a piece of wood make an excellent " strip," particularly if the flexible cable end is laid in the groove so that the lead is cast on to it. There is some advantage in first tinning the end of the cable.

The auxiliary anode is applied by attaching the end of the cable to the anode rod and holding the anode in the hollow or recess in the work whilst it is in the vat. Rubber gloves should be used for this purpose if the anode is held by the operator. In some cases the anode cable can be suspended from the cathode rod if a strip of rubber is interposed to prevent short-circuiting.

Difficulty is sometimes experienced in applying a second deposit of chromium on top of the first. This may be necessary when the first attempt at a difficult job does not meet with success and patches of nickel are left in the deepest parts. In a case like this the second deposit often assumes a matt surface instead of the required brilliant finish. In most cases, provided that no polishing of the first coat has been attempted, the trouble may be overcome by suspending the work in the vat for a few minutes until it has reached the same temperature as the solution, when the current may be gradually applied. Work should never be introduced into the vat unless there is a potential difference between the vat terminals of about 3 volts.

Wood, plastic wood, or good-quality rubber may be used for plugging holes or crevices in the work when their presence is responsible for patches of nickel, as frequently happens. Rubber often serves a useful purpose in " stopping off " some part of the work which is not required to be plated, or which must be protected from the acid. The red rubber from which motor-car inner tubes are made is a good grade to use, and scrap tubes form a cheap source of supply.

Racking and wiring operations can often be eliminated by the application of a little ingenuity. Thus, in the case of the ordinary heating-installation globe valve, the tail piece or nipple, which would normally be treated as a separate item, may be screwed into the female thread of the valve body, and the two can then be plated as one part without in any way affecting the efficiency of the process. Similarly, many opportunities arise for inserting screws into their respective holes, particularly on reconditioning jobs.

It is preferable that chrome vat bars should be made in such a manner that the work and the anodes may be disposed in any desired fashion. This is usually achieved by fixing longitudinal bars to the top of the vat and allowing cross bars to rest on them. These cross bars may be placed in any desired position on the bars running lengthwise and many an awkward job can be satisfactorily dealt with by making use of this facility, especially if spare bars are kept available.

Scrupulous cleanliness of the bar contact faces is essential, however, if trouble is not to arise from this source, since the heavy currents used soon cause overheating and burning where any faulty contact occurs. So heavy are the currents employed that, despite the fact that the electrode bars are usually made from solid copper of about 1 in. in diameter, it is desirable on very long vats to have the current supplied to both ends of the bars in order to minimise the voltage drop.

The action of the acid is sufficient to remove slight traces of grease which remain on the surface of the nickel plating, but when jobs have been handled, the fingermarks often show through the chrome deposit. To avoid this it is desirable that the work be wiped after racking or wiring. A satisfactory agent for this purpose is powdered lime.

The first swill after the chromium-plating bath, originally filled with water, soon becomes a weak solution of chromic acid due to the transference of the latter from the plating bath. In order to minimise waste, this " drag-out " is used for topping-up the plating solution. It is generally recommended that the drag-out be kept hot, but from the point of view of efficient swilling a cold drag-out

is to be preferred. This is because the hot plating solution raises the temperature of the work, and when it is plunged into the cold drag-out, the pores of the metal contract and "squeeze" out the solution which they contain. The swill which follows the drag-out contains washing soda to neutralise the acid, and as it is hot the pores expand and permit the entry of the soda solution. This swill is followed by a rinse in running cold water and a final swill in hot water to dry out the work.

Some castings are extremely porous, and great difficulty is experienced in removing every trace of acid. It is imperative that this be carred out as efficiently as possible, since even slight traces of the solution have a corrosive effect on the base metal, especially if this be non-ferrous. Parts assembled for plating purposes should be taken apart for swilling if there is any chance of acid being trapped anywhere. Similarly, hollow articles such as towel-rails should receive particular attention, as it is a simple matter to leave an appreciable quantity of solution in a part which is difficult of access.

Stripping.—It is often necessary to remove a deposit from an article, generally because the deposit is faulty or in need of renewal. The process of removal is termed stripping, and is essentially the reverse of plating. The most convenient way of stripping nickel, for example, is to make the work the anode in a solution of sulphuric acid, using lead sheets as cathodes. The nickel passes into the solution with the aid of the current flowing through the vat, and the entire deposit can be completely removed. In addition to sulphuric acid there are certain proprietary solutions which claim some degree of superiority. If the articles are greasy, a preliminary degreasing operation is necessary or the results will be patchy. As soon as the deposit is stripped off, the work should be removed from the vat, as prolonged treatment results in a rough surface on the base metal.

Electrolytic stripping is far superior to removing the deposit by polishing, which is very laborious and almost impossible where the surface is anything but plain.

Chromium can conveniently be removed from non-ferrous metals by simple immersion in hydrochloric acid. The same method can be adopted for ferrous metals, but it is not to be recommended as they are attacked by the acid. A better way is to make the work anodic in a solution of caustic soda in a steel tank, the latter being the cathode.

Care should be taken in electrolytic stripping and cleaning operations to switch off the current before removing any of the work or disturbing the suspender contacts with the electrode bars. The large quantities of gas evolved frequently cause a froth to form on the surface of the solution, and as this froth is charged principally with hydrogen and oxygen, a spark from a broken contact will often result in a startling explosion. This in itself is not usually dangerous, but the splashes of solution which are thrown out when it occurs can easily cause injury to the operator.

Whenever powerful acids are used for stripping purposes it is a good plan, after the first water swill, to rinse the work through a solution of washing-soda to neutralise any lingering traces of acid which might remain. This is particularly important in stripping chrome deposits in hydrochloric acid, as the introduction of this acid into the chrome solution has fatal consequences. Instances arise where hollow articles have no particular holes in them, but are, nevertheless, anything but watertight because of small crevices or badly made joints. (Tubular handles are an example.) In a case of this sort it is advisable to drill at least one drainhole of, say, $\frac{1}{32}$-in. diameter in a convenient place. If this is not done, solution will find its way inside and will percolate through the crevices for a considerable time after the plating is carried out. This, of course, applies equally to any operation where immersion in a solution is involved.

Current Supply.—Because of the high current densities and low voltages required for electroplating, specially designed plant is necessary to convert the usual industrial supply into a suitable form. Although the potential difference required across the vat terminals is seldom in excess of 6 or 8 volts for most purposes, an output of 4,000 amps. or over is not an uncommon demand for a cleaning and plating installation. This does not include the chromium-plating vats, which require individual sources of supply. Cleaning and stripping vats can be run satisfactorily straight off the main leads with a simple knife switch to break the circuit. Plating vats usually have a control board with several resistances, and a corresponding number of knife switches for controlling the current.

Many of the generators and dynamos in use operate on the shunt principle for control of the output. A more advantageous system is that of separate excitation in which a supply of direct current, from an external source or from a small dynamo driven from the generator shaft, feeds the generator field circuit and is controlled by a rheostat. This system is particularly applicable to the generators for chrome plating, where accurate and sensitive control of the current is essential.

An alternative method for which a number of advantages are claimed is rectification of the industrial supply by means of Westinghouse rectifiers, used in conjunction with step-down transformers. The most noteworthy feature of this arrangement is the absence of moving parts and correspondingly low maintenance costs.

Whatever the source of the current supply it should be situated in such a manner that the minimum length of mains lead is required, as the power losses over excessive distances are appreciable. The mains leads themselves should be made of high-conductivity copper bar, and all joints should be made with suitable couplings and tee pieces thoroughly soldered in position.

Dust and fumes from the plating shop must be kept away from the generators. The housing of the latter in a separate room is to be recommended.

Heating the Vats.—Many of the solutions in a plating installation require to be heated. Of several methods which exist, low-pressure steam heating is undoubtedly the best proposition for large plants, both from the point of view of economy and convenience in working. Low-pressure boilers as manufactured for central-heating installations are well suited to this purpose and in many cases the ordinary cast-iron radiator can be used to advantage, particularly in hot-water swills. The usual method is to employ heating coils of iron pipe which lie on the bottom of the vat. These are suitable for hot-water swills and alkaline solutions, but acids demand lead-covered pipes.

A point which requires careful attention is the insulation of every heating coil (or air-agitation coil and filter apparatus) from the remainder of the vats which run off the same pipe lines. This can be effected by using flanged couplings with insulation bushes through the bolt holes, insulation washers under the bolt heads and nuts, and a non-conducting jointing material between the flanges.

Steam can also be used for heating vats, and a steam heating-coil requires a steam trap to prevent the passage of steam into the return circuit. If the installation incorporates an automatic return pump for the condensate, it is possible to leave the boiler to its own devices, brief attention at intervals of an hour or so being sufficient.

Electricity can be used for heating purposes in three different ways. These involve the use of heating elements in suitable protective sheaths for laying on the bottom of the vat, the use of simple immersion heaters, and the attachment of a heating element to the outside of the tank (when this is made of steel). In districts where power is cheap, or in cases where the plant is not very large, electricity provides a very convenient source of heat.

Heating by gas is achieved either by heating the underside of the tank, burning the gas in tubes passing through the solution, or by external heating in a special unit which is fitted with two pipes, one to draw cool solution from the bottom of the tank and the other to return it to a higher level after heating. The circulation in the latter case is effected by the convection currents set up by the heating process.

When the tank bottom is heated directly by gas it is advisable to fit baffle plates to protect the tank from excessive local heating.

Another method of heating which finds application is the use of oil, which can be burnt in the familiar type of vaporising burner.

Vat Arrangement.—Thought should be given to the arrangement of the vats to suit the progress of the work. Much time can be lost by dodging about from one tank to another when these are not arranged in an orderly sequence. Thus it is often an economy to install a water swill for use after each operation, where this is called for, rather than to make one swill serve for several purposes, as often happens with small plants.

Avoiding Health Troubles.—Of the difficulties affecting the health of the operators of most plating processes, the majority are amenable to ordinary treatment. This is not strictly true of chromium-plating, but whilst the acid used is very persistent in its action and care must be taken to avoid trouble, the operation of the plant is by no means as hazardous as many imagine.

Now that the erection of an efficient spray exhaust system is compulsory, the chances of the acid in the atmosphere having an adverse effect on the personnel are reduced to a negligible factor, and troubles similar to many which have occurred in the past should not now be experienced.

This leaves actual contact with the liquid to be dealt with.

Protection of Workers.—The most obvious precautions in this respect include the provision of really waterproof gear. To resist the acid, good-quality rubber is necessary, and knee boots, aprons and gloves should conform to this standard. Suitable boots of a reputable make are obtainable almost anywhere, but the aprons and gloves must be chosen with care. The former should not be too thin or they will soon wear through. (Even the best rubber slowly deteriorates in chromic acid.) On the other hand, a heavy apron is a burden to the wearer, hence the recommended maximum thickness may be set at $\frac{1}{8}$ in. It is sometimes economical to purchase sheet rubber and cut and eyelet this to make aprons as required.

Special seamless gloves with long gauntlets can be obtained for protecting the hands and the necessity for using these when working on the solution must be emphasised. Gloves *must* be repaired or replaced immediately they show signs of leakage.

CHEMICAL COLOURING OF METALS

Polishing and Cleaning.—It is of the greatest importance that all metal objects selected for chemical colouring be perfectly clean. The object should first be polished. Then it should be degreased. Finally, it may be advisable to dip the metal object in a bath of warm dilute hydrochloric acid (spirits of salts) for a minute or two in order to scour it thoroughly. After this treatment, the object is rinsed in warm water, and is then ready for "bronzing."

If a metal object is not scrupulously clean, its subsequent colouring will very frequently be patchy and uneven. Also, the colouring may not be permanent. Hence, it will be clear that a thorough cleaning of the metal object before "bronzing" or colouring is an essential to the success of whatever process may be used, and in all the instructions for chemical colouring given in this section it will be assumed that the metal object undergoing the process has previously been thoroughly cleaned and, indeed, scoured.

Dead-black Surface.—Most common metals can be given a dead-black surface coloration very readily by chemical means. For instrument work, such a coloration is very useful and often, indeed, a necessity. The black colour, unlike many of the painted-on lacquers, does not flake off or chip away. Brass and copper articles can be blackened by immersion for a few minutes in the following liquid:

Copper nitrate	1 oz.
Water	3 oz.

A small quantity of silver nitrate dissolved in the above solution is said to improve the black coloration produced upon the metal, but its employment is by no means essential.

Copper (but not brass) articles may be made to acquire a slightly shiny black surface by immersion in the following solution:

Ammonium sulphite (liver of sulphur) .	1 part
Water	4 parts

Brass articles take upon themselves a steely-grey colour in this solution.

By immersing iron articles in a solution of photographers' "hypo" they are given a blue-black colour, particularly if a little lead acetate or nitrate is dissolved in the hypo. Silver immersed in sodium-sulphide solution turns almost black, while a black colour on zinc can be obtained by immersing it in a solution of antimony chloride.

A pleasant grey colour is produced on iron by boiling it for half an hour in a weak solution of iron phosphate. This process is akin to that of "coslettisation," a thin film of iron phosphate and oxide being formed on the surface of the metal.

In order to colour brass or copper a variety of shades ending in black, the metals should be immersed in a very dilute solution of ammonium or sodium sulphide. Brass, for instance, placed in an extremely dilute solution of either of these sulphides will acquire a golden appearance, whilst copper, in the same solution, will be reddened. By making these sulphide colouring solutions stronger or by allowing a longer time for them to act upon the metal, the mechanic will find that he can get almost any yellow, red, brown, or black colour he desires on these metals.

Steel articles can be " blued " simply by passing them through a flame. Better still, they may be blued by boiling them for a short time in a strong solution of hypo containing a little lead nitrate.

Antique Effects.—The production of antique effects on articles of brass and copper enhances the appearance of certain work, since by careful working, beautiful effects on these metals can be obtained fairly readily. The green or brown coloration which an article of brass or copper usually acquires by age and from exposure to the elements is termed a " patina," the word signifying an encrustation. Copper, bronze, and brass patinas can be divided into two varieties, namely green and brown. The latter is the easier to imitate by chemical means. If, for instance, an article of copper is dipped in a dilute solution of sodium sulphide, it will instantly acquire a brown patina, the exact shade and depth of the coloration being dependent upon the strength of the sulphide solution. Brass acquires a good patina of the brownish variety when it is heated in a paste made of sulphur and lime.

The green patina which is often seen on brass or copper articles of great age, and which is often very beautiful in appearance, consists, for the most part, of a layer of copper carbonate. We may obtain such a patina on brass and copper articles by burying them in damp earth for a considerable period. Such a process, however, is a slow and an uncertain one.

Green Patina.—An excellent green patina can be given to copper and brass objects by suspending them from some improvised wooden stand and then placing them in an airtight container. Within the container is placed also a small vessel containing some ordinary washing soda or bicarbonate of soda, together with a little water. The metal articles are brushed over with strong vinegar, or, better still, with dilute acetic acid, and a little of the acid is poured into the soda-containing vessel, the container then being immediately closed up. The carbon-dioxide gas evolved from the soda-acid mixture will react with the acetic acid on the metal articles, and gradually the latter will acquire a yellow-green coloration and a hard shiny surface.

The operations mentioned in the above paragraph should be repeated every alternate day until the metal articles have been sufficiently coloured, a task which will occupy about two or three weeks.

A quicker method of obtaining a green colour upon brass or copper articles consists in painting them over daily with the following solution:

Copper carbonate	3 parts
Sal-ammoniac	1 part
Common salt	1 part
Copper acetate	1 part
Cream of tartar	1 part
Strong vinegar	8 parts

This solution gives a blue-green coloration which takes about four complete days to develop.

Quite a good yellow-green coloration may be obtained on copper and brass (particularly the latter) articles by brushing them over daily with a mixture of vinegar, common salt, and ordinary sugar.

Note that for the production of these antique green colorations the metals must not be immersed in the solutions, but merely brushed over with them.

Dulled Aluminium.—The silvery appearance of aluminium is not always desirable. It may, however, be permanently and uniformly dulled by dipping the metal in a hot, moderately strong solution of caustic soda (sodium hydroxide) for a few seconds. The metal will thereafter have a matt appearance. If aluminium so treated is immediately rinsed in warm water and then immersed in a hot solution of an aniline dye, the aluminium surface will take up a little of the dye-stuff, and will become permanently tinted. This constitutes an imitation of the now well-known process of " anodising " aluminium and the subsequent " dyeing " of the metal.

By immersing zinc in a hot solution of ammonium molybdate containing a little free ammonia, a deposit of metallic molybdenum will be obtained on the surface of the zinc. This " molybdenum-plated " zinc has a very fine colour, ranging from an iridescent golden yellow to a steely brown. Aluminium articles can be made to acquire a dusky hue by the same process.

What is known as " oxidised silver " is simply silver which has been immersed

in a weak solution of liver of sulphur (potassium sulphide) containing a little ammonia. Very weak solutions produce the best results, for in strong solutions the silver is merely blackened.

Similarly, nickel-plated articles may be "oxidised" by immersion for a few seconds in the above solution, in which they usually acquire a dark golden tint.

Brass articles may be made to acquire an extraordinary series of colorations ranging from pale gold to pink and pale blue simply by immersing them in a solution containing half an ounce each of lead acetate and "hypo" (sodium hyposulphite) to the pint of water.

Permanent Coloration.—It is difficult to get good permanent colorations on tin objects. If, however, a sheet of tin is heated to near its melting-point and is then suddenly plunged into the following solution, nitric acid, 1 part, sulphuric acid, 10 parts, water, 89 parts, the surface of the metal will acquire a very beautiful crystalline appearance to which the term *moiré metallique* (watered metal) has been applied.

Mottling Metal.—The mechanical method, as employed on faceplates, machine tools, etc. The articles are finished dead smooth first, and then, with a tool similar to the ground-off end of a broken file (ground with a cutting edge), take off an infinitesimal portion of the surface of the plate or other article. The tool is held at an angle of about 35 degrees to 40 degrees, and the operator uses either a circular motion or an irregular backward and forward motion. The work is continued until the whole surface of the plate, etc., is beautifully mottled with wavy lines or patches as desired. A chemical method of producing a mottle of brown and green is to subject the thoroughly clean work to the action of a boiling solution of 8 oz. copper sulphate and 2 oz. sal-ammoniac in 1 gal. of water. When a brownish colour appears, transfer the work to a solution (cold) of 4 oz. sal-soda in 1 gal. of water, floating on the surface of which second solution is some oil or petrol. On replacing the work in the first solution a green colour appears; but owing to the oil which spreads over the surface of the work, the actions of the two solutions are not even, and the colours become mixed.

Oxidised Finish.—Iron articles may be oxidised by heating them to redness and then holding them in a jet of steam escaping from a kettle of boiling water. This process is, indeed, the basis of the Bower-Barff process of rustproofing iron and steel articles. By means of it, the iron becomes coated with an extremely fine layer of black iron oxide which resists all further oxidation. On a small scale, this method of rustproofing is suitable only for treating nails, screws, and other small articles which can be conveniently held in a small steam jet after being heated to redness.

Coslettising and Parkerising.—The method of coslettising is carried out in the following manner. The coslettising bath is heated by being rested over a saucepan containing boiling water. The articles to be coslettised should be immersed in the bath for about half an hour, being frequently turned over in order to ensure that the chemical action takes place equally over their surfaces. The steel and iron articles turn grey almost immediately after they have been immersed in the bath. Bubbles of hydrogen gas are evolved from their surfaces, but the metalwork is not dissolved away.

After half an hour's immersion in the hot (nearly boiling) coslettising bath, the articles should be withdrawn, well washed in water, and dried. At this stage they will have a grey colour, but on being rubbed over with oil they will acquire a soft dull-black finish and will be absolutely rustproof. The fine "film" formed on the metal surface is composed of a mixture of iron phosphate and iron oxide. This protecting "skin" is so exceedingly thin that it follows the contours of every microscopic irregularity on the metal surface. Yet it is hard, tough, and extremely wear-resistant.

Coslettised iron and steel may, of course, be painted, varnished, or enamelled, such surface films adhering extremely well to the treated metal surface.

The commercial rustproofing process known as "Parkerising" is merely another form of coslettising, and was originally developed in America by the Parker Company of Detroit. It consists essentially in the employment of a patented mixture of iron and manganese phosphates in the rustproofing solution. Another similar modification is the process known as "Bonderising," which is commercially employed to form a base-coating on iron and steel for finishing with paints and lacquers.

MILLING AND MILLING MACHINES

Modern milling machines are of several distinct types; each is fundamentally the same in principle, but vastly different in construction and the class of work they are called upon to perform.

Column and Knee-type Machines.—These machines are perhaps the best known of all the range of different types of millers, and consist of three general styles—the universal machine (Fig. 1), the plain machine, and the vertical-spindle machine. The first two are commonly referred to as "horizontal" machines, while the vertical-spindle style are simply referred to as "vertical millers."

The main difference between the universal milling machine and the plain machine is that on the universal the table swivels horizontally, and each universal machine carries with it as part of the general equipment the universal index centres, more commonly known as the "dividing head," which plays an important part in the majority of universal milling work, as in the cutting of the spirals, gear cutting, etc., all of which will be dealt with later on.

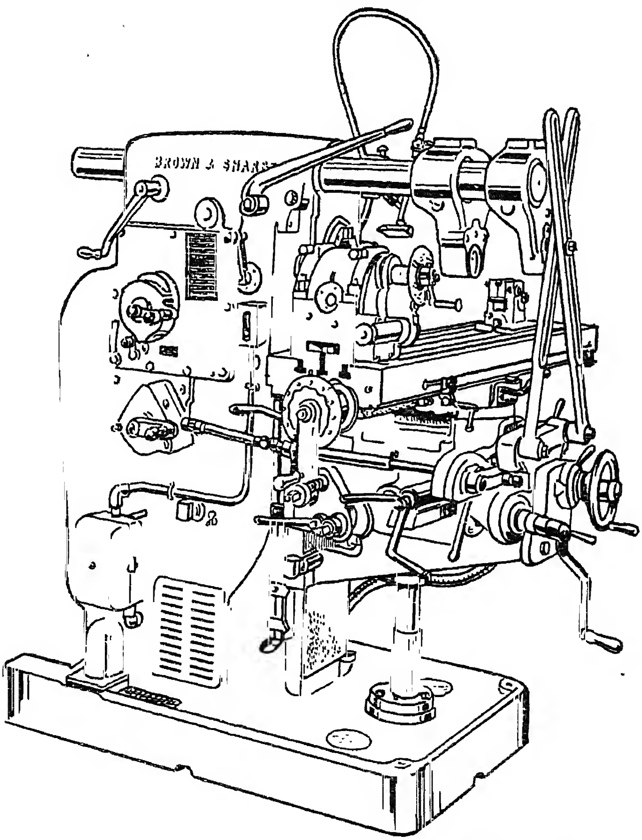

Fig. 1.—Brown and Sharpe dual-control type universal milling machine.

In the plain machine the table is fixed and does not swivel to a desired angle, and universal index centres are not supplied as part of the machine. These machines are usually built for production work, where ease of setting up is important, and are equally useful on either large or small lots of work, where speed and accuracy are essential.

The vertical miller's main difference from the plain machine is that instead of the spindle being in a horizontal plane, it is mounted vertically above the table, and adjustment can be made in height of both the table and the spindle in relation to the work being done.

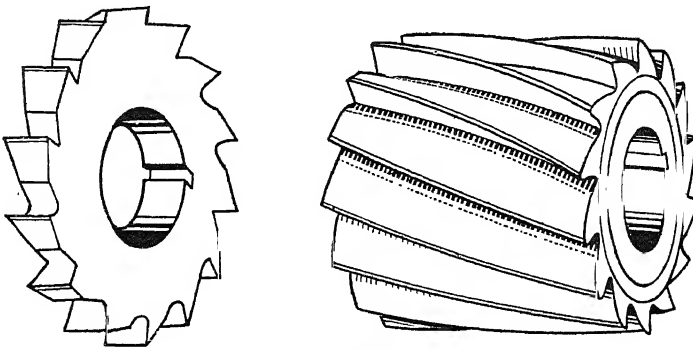

Fig. 2.—Plain cutters.

Extremely accurate work can be done on these machines with end-mills running at high speeds, the depth of cut being controlled by the adjustment of the spindle head.

Bed-type or Production Machines.—These machines are usually of more rigid construction than the previous ones mentioned, and are, as the name indicates, used on all classes of production work which call for heavy cuts and fast rates of speeds and feeds.

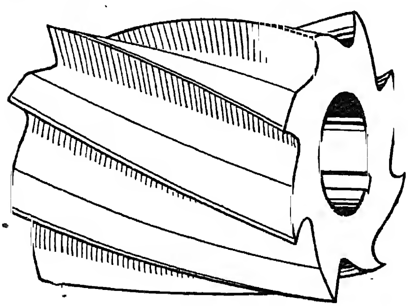

Fig. 3.—Coarse-tooth milling cutter.

The general principle of the machine is that the bed is fixed, and the arbor carrying the cutters can be moved in a vertical plane in relation to the work. This machine is particularly adapted to very long runs of work, and can easily be utilised as a semi- or a fully-automatic machine.

Another variety of the bed-type machine is the "Duplex" miller, which carries two cutter heads instead of one, operating opposite each other, with the table between them. It will readily be seen that a machine of this type can handle many jobs—milling two sides or faces simultaneously.

Plano-millers.—These machines are for exceptionally heavy-duty work, and are to be found only in the shops where large castings and forgings have to be machined—they are particularly used for long-run slabbing operations, as the name indicates.

Cutters.—Before attempting any milling operation, the operator should consider the method and the cutters he has on hand for doing the job. A milling job can perhaps be done in several different ways, but it lies with the operator to choose the method which he knows will suit what cutters he has on hand, and which method will produce the best results.

Types of Cutter.—Perhaps the most common of all milling cutters is the "slab"-mill, which is made with either plain or spirally cut teeth, and is used for milling flat surfaces in a horizontal plane (Fig. 2).

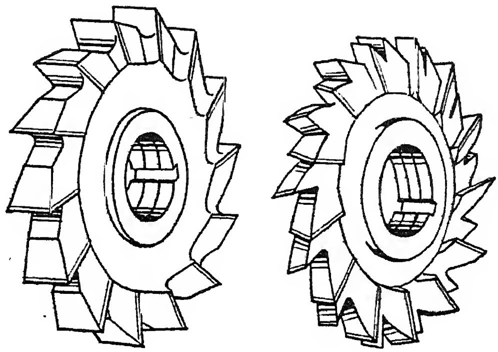

Fig. 4.—Side-and-face staggered tooth cutters.

The designs of these cutters vary considerably—modern milling practice demands slab-mills that will take heavy cuts and at the same time produce a good finish. A well-known cutter of this type is the "coarse tooth" type (Fig. 3), which has a fairly steep angle of spiral and from six to eight teeth. This cutter produces an excellent finish on fairly heavy cuts.

For very heavy roughing cuts a helical cutter should be used, with as few teeth as possible.

Side-and-face cutters come next. These cutters are made with teeth on the side as well as on the periphery, and are extensively used for ending slot-milling and a variety of other operations where two faces can be milled simultaneously. It may be said that these cutters are usually made in two styles—plain and "staggered" teeth.

The staggered tooth cutter (Fig. 4) has the teeth gashed angularly to it periphery, and with a large angle of rake these cutters can take exceptionally deep cuts with ease.

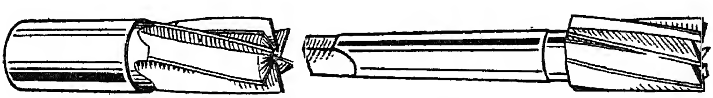

Fig. 5.—Straight and taper shank end-mills.

For operations where it is not accessible to use either a slab-mill or a side-and-face cutter, an end-mill may be used (Fig. 5). These cutters are made in all sizes, the larger ones having a taper shank end to suit the machine, and are very useful on such operations as facing bosses, milling radii, etc. Face mills are usually large-diameter cutters—preferably with inserted teeth of tungsten carbide—and their chief use is on the facing (as the name implies) of large surfaces. Extremely good finishes and accuracy can be obtained with this type of cutter.

Stock-formed Cutters.—These cutters differ in one important respect from the usual variety of milling cutters. They are so made that they can be ground on the front of the tooth without altering the form of the cutter. The most

common forms of stock-formed cutters are the convex and concave types and the corner-rounding or half-radius cutter (Fig. 6). These cutters are usually made with a straight gash, but on many specially shaped or formed cutters a spiral gash proves more effective.

For all sawing operations, or for milling narrow, deep slots, a milling "saw" is used. In reality this "saw" is a cutter with plain teeth, ground on the periphery. For heavy slotting cuts a saw with side-chip clearance is recommended, as this type is not inclined to stick so much as an ordinary plain saw, and breakages are less frequent.

A good plan for milling slots with safety with a plain saw is to have two washers—one each side of the saw—about ¼ in. thick, and of the largest diameter possible in relation to the slot being milled. This tends to strengthen the saw, and in the event of a breakage the pieces will not fly, as they are apt to do if no precaution is taken.

For the milling of T-slots and similar jobs the T-slot cutter is used, which may have either a plain or a tapered shank. In this case the T-slot is first milled with an ordinary side-and-face cutter, and followed with a T-slot cutter.

Gear cutters, which really belong to the formed-cutter variety, are very accurately made cutters of involute form having teeth of the exact pitch of the required gear to be cut. They usually are made in sets of eight for each pitch, numbering one to eight, depending, of course, on the number of teeth to be cut.

Another form of cutter which takes an important place in the milling of intricate shapes, where a specially formed cutter is not warranted, is the fly-cutter. This may consist of one to four separate teeth rotating in a special holder; in reality they work like a slotting tool. It may be seen that fly-cutters must be used with care, and to produce good results studied speeds and feeds are essential.

If clearance is too great on a cutter, "chattering," or vibration between the cutter and the work, will result, and great injury may be done to the work-piece and the machine if this is not quickly corrected.

Therefore, cutters with too great a clearance rake should be reground, and particular attention should be paid to the clamping or holding of the work-piece, and to whether the overarm steadies, if in use, are correctly clamped in the column. Play in the arbor-yoke bushes or slack table and knee gibs may also cause chattering.

Mount cutters as near as possible to the column face—this will ensure maximum rigidity under cut, and will not strain the arbor or put undue stress on the machine.

Make sure the work-piece is firmly clamped in the vice or held by straps to the machine table. If located on parallels in the vice, make sure it seats on both parallels when the vice is tightened up.

Oil all wells regularly and see that the arbor-yoke bushes have a plentiful supply of oil, and that there is no dirt or chip particles between the bushes and the arbor collars.

Before putting spacing collars on the arbor, wipe arch bearing face carefully. Any dirt or chips between these will obviously cause a spring when the arbor nut is tightened and consequently the arbor will run out of truth, which will affect the arbor bearings, the finished work and the machine.

Cleanliness is essential to good milling work. Don't let chips remain in a heap on the table. Clean them off systematically after each pass of the cutters.

Always take a preliminary cut first, and ascertain how much more metal has to be removed to bring the job to the finished size. A good way of setting a cutter for depth is to bring the work up under the cutter until it contacts a piece of rice paper held on top of the job. The table is then withdrawn and raised the required amount. This method is not meant to be dead accurate, but it keeps the operator on the safe side of the limit, anyway.

Above all, keep clear of the machine while it is in motion. Be near enough to stop it should anything go amiss, but never work on the wrong side of the machine if you can avoid it.

Use plenty of coolant when milling steel and other such metals. Paraffin gives an excellent finish on duralumin and other alloys. Brass and cast iron are best milled dry. Use a small brush or other instrument to remove coolant and chips—never touch them by hand.

Universal Index Centres.—The attachment known as the universal index centre, or the "dividing head," is indispensable to the universal milling machine. It is chiefly used for cutting spirals, gear cutting, cam cutting, graduating or on any form of work where the periphery has to be divided into a number of equal parts.

The most simple form of dividing head consists mainly of a casting carrying a spindle attached to a worm and wheel. Rotation of the spindle is effected by a crank connected to the worm, as in Fig. 7.

Together with this part of the dividing-head equipment, which is known as the headstock, is the tailstock, or footstock centre, which acts as a support for the outer ends of long cylindrical work-pieces, or work mounted on mandrels or held in the dividing-head chuck.

The footstock consists of a body casting on which is mounted an adjustable centre, which can be adjusted both longitudinally and vertically in relation to the work. In most cases the footstock can also be set at a desired angle to the base and in alignment with the headstock centre as in the milling of drills, tapered pieces, etc.

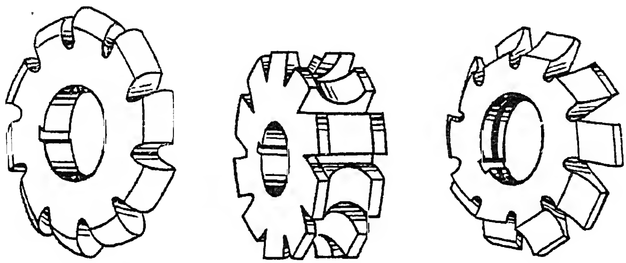

Fig. 6.—Formed cutters. (*Left*) Convex ; (*centre*) concave ; (*right*) corner rounding.

A handy little gauge for the setting of both headstock and footstock centres is shown in Fig. 8.

The fundamental action of the dividing head is to divide the periphery of a piece of work into a given number of equal parts.

This is done by rotating the spindle by means of the crank handle in correct relation to a certain number of holes in the dividing plate. It may be said that there are two practical and accurate methods of indexing in use to-day, namely plain and differential, which we will deal with in turn.

Plain Indexing.—Plain indexing simply consists of turning the index crank a given number of turns to make the work rotate one complete revolution.

Now, as the usual type of dividing heads have a worm-wheel containing 40 teeth and a worm that is single threaded, it will be seen that one complete turn of the worm (or index crank) will rotate the worm-wheel (which, in turn, rotates the spindle) one-fortieth part of a complete revolution. Knowing this, it is fairly simple to calculate how many turns or fractions of turns of the index crank are required to give a definite number of divisions or parts of a complete revolution of the spindle.

For example, to cut 40 equally spaced teeth in a gear-wheel, it will be necessary to rotate the index crank one complete turn for each tooth, or 40 turns altogether for the finished gear. Likewise for a 20-toothed wheel, the crank would be rotated twice for each tooth, thus making 40 complete turns, or one complete turn of the headstock spindle.

This rule applies quite easily when the number of divisions required is divisible into 40. When not, however, it is quite simple to obtain the required divisions by utilising one of the index plates which are supplied with the headstock.

Dividing Plates.—These plates are usually supplied in sets of three, and consist of round metal plates, with holes drilled in circles—each circle containing a different number of holes.

The plates are usually made as follows, and contain circles with these numbers of holes:

Plate 1.—15, 16, 17, 18, 19, 20.
Plate 2.—21, 23, 27, 29, 31, 33.
Plate 3.—37, 39, 41, 43, 47, 49.

To mill a ratchet with 9 teeth.

$$\frac{40}{9} = 4\frac{4}{9}$$

As there is not an index plate with as few holes as 9, multiply through with a common figure:

$$4/9 \times 3 = 12/27.$$

Therefore, to get 9 teeth select an index plate containing a 27-hole circle. For each tooth the index crank is rotated four complete turns and an additional 12 holes in the 27-hole circle.

The correct method of spacing holes is to place the pin of the index crank in a hole in the 27-hole circle, and then space off 12 clear holes, not counting the one the pin is in. When this has been done, the index sector should be set to encompass the 13 holes as in Fig. 9.

Differential Indexing.—This method of indexing is rather more complicated than the plain method, because additional gear wheels are introduced to connect the index plate and the headstock spindle.

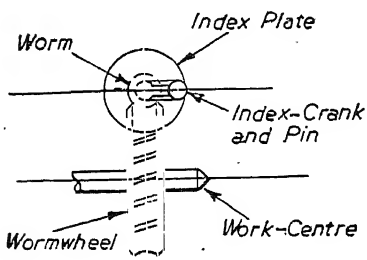

Fig. 7.—Principle of the dividing head.

For differential indexing, the index plate moves with the crank, so the operator should be careful to see that the retaining pin of the index plate is disengaged before he commences.

Differential indexing is invaluable because of the large number of divisions that can be obtained by its use, in fact any number of divisions between 1 and 382 can be obtained with the set of change-gears usually issued with the set of index plates mentioned previously. With additional change-gears many divisions beyond 382 can be indexed successfully.

Using the differential method, then, the headstock spindle is geared to the index plate by a train of gearing which is selected to give the required number of divisions.

Following is the formulæ for finding the ratio of the gearing between the headstock spindle and index plate, together with an example showing how to select gears to produce 77 divisions.

N = Number of divisions required.
H = Number of holes in index-plate circle.
n = Number of holes taken at each indexing.
V = Ratio of gearing between index crank and spindle.
x = Ratio of the train of gearing between spindle and index plate.
S = Gear on spindle
G1 = First gear on stud } Drivers.
G2 = Second gear on stud
W = Gear on worm } Driven.

$$x = \frac{HV - Nn}{H} \text{ if HV is greater than } Nn.$$

Similarly,

$$x = \frac{Nn - HV}{H} \text{ if } Nn \text{ is greater than HV.}$$

Or,

$$x = \frac{S}{W} \text{ (Simple gearing).}$$

$$x = \frac{S\ G1}{G2\ W} \text{ (Compound gearing).}$$

Therefore, if $V = 40$ (standard ratio between index crank and spindle) and we have plates with the number of holes as stated previously, and gears with the following number of teeth, 24 (two gears), 28, 32, 40, 44, 48, 56, 64, 72, 86, 100, we can find the ratio required.

Example:

$N = 77$. Required, H, n and x.
Assume $H = 20$, $n = 10$.

$$\text{Then } x = \frac{(20 \times 40) - (77 \times 10)}{20} = \frac{30}{20} = \frac{3}{2}.$$

The ratio of 3/2 thus obtained can be expressed as follows: 48 and 32, the 48-toothed gear being the gear on spindle, and the 32 one being the gear on the worm. As this is only a combination of two gears, the gearing is "simple," requiring one idler.

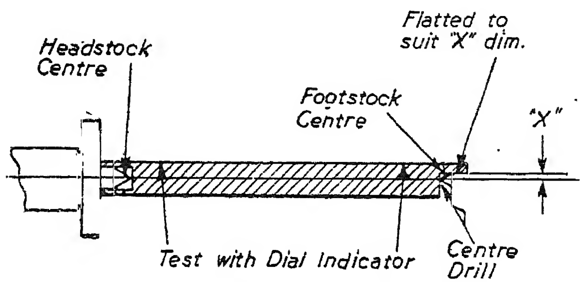

Fig. 8.—Gauge for setting headstock and footstock centres.

If a ratio cannot be obtained with two gears, then four are used, and the gearing is known as "compound."

Here are the formulæ for determining how many idlers to use on simple and compound gearing:

When HV is greater than Nn, and the gearing is simple, use one idler.
When HV is greater than Nn, and the gearing is compound, use no idlers.
When HV is less than Nn, and the gearing is simple, use two idlers.
When HV is less than Nn, and the gearing is compound, use one idler.

Nowadays, however, most of this calculation is unnecessary, as all leading milling-machine makers issue special charts for the rapid selection of change-gears, for producing any number of divisions from 1 to 382. The charts give all the data required, including how many idlers to use, if required. Fig. 10 shows the dividing head geared for 319 divisions, using one idler.

It is important to note that when the dividing head is geared for differential indexing, it cannot be used for cutting spirals, as this operation calls for the gearing of the head to the table lead screw.

Cutting Spirals.—The most common form of spirals cut on the milling machine are milling cutters, spiral gears, twist drills and special reamers. Worms are sometimes cut also, but they require the use of a universal vertical milling attachment.

To produce a spirally cut piece of work, the work has to be rotated while held in the dividing head, and this is accomplished by gearing the table lead screw up to the worm of the dividing head, which in turn rotates the chuck or centre holding the work-piece.

There are four change-gears used in cutting spirals, and these are :
Gear on screw.
First gear on stud. (Always first to be put on.)
Second gear on stud, and gear on worm.

The gear on screw and the first gear on stud are the driving wheels, while the second gear on stud and the gear on worm are the driven wheels.

The principle of spiral-cutting calculations is similar to that of the screw-cutting lathe ; i.e. the compound ratio of the driven to the driving wheels equals in all cases the ratio of the lead of the required spiral to the lead of the machine.

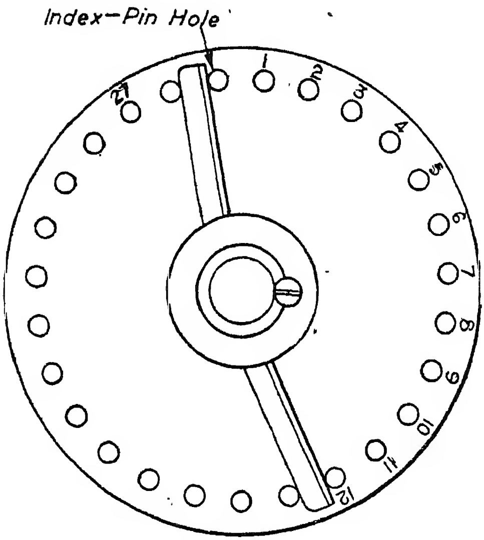

Fig. 9.—Index sectors set for 12 holes in 27-hole circle.

It will be readily seen that different combinations of change-wheels will give a different ratio of the longitudinal movement of the table to the rotary movement of the work. Thus different leads of spirals can be obtained by varied use of the change-gears on hand.

Following are the formulæ for calculating change-wheels necessary to cut a given spiral.

Note the ratio of the required lead to 10.

(*Note.*—Ten is always the lead of the table screw ; i.e. if the lead of the required spiral is 14 in., 14 to 10 will be the ratio of the required gears. This gives the compound ratio between the driven and the driving gears.)

Having found this, express the ratio as a fraction, resolve this fraction into two factors, which can be raised to higher terms to correspond with the number of teeth of the gears that are available for use. The numerators represent the driven and the denominators represent the driving wheels that will produce the required spiral.

Example.—Assume that a spiral of 12-in. lead is to be cut.

$$\text{Ratio of required lead} = \frac{12}{10} = \frac{3}{2} \times \frac{4}{5}$$

which when multiplied by suitable factors gives us $\frac{72}{48} \times \frac{32}{40}$, so gears with 72, 32, 48, and 40 are selected to give the required spiral.

The numerators of the fractions represent the driven gears, and the denominators represent the driving gears. Formulæ for finding what spiral may be cut by any given change-gears :

$$\frac{\text{Product of driven gears} \times 10}{\text{Product of drivers}} = \text{Lead of spiral.}$$

Example.—What spiral can be cut by gears with 48, 56, 64, and 100 teeth, the first two being the driven gears ?

$$\begin{array}{l}\text{Spiral to be cut}\\ \text{(or lead of spiral)}\end{array} = \frac{48 \times 56 \times 10}{64 \times 100} = 4{\cdot}200 \text{ in. to 1 turn.}$$ Thus it will be seen how the necessary gears are selected to cut either a given spiral or to determine what spiral will be cut by a given combination of gears.

As explained for differential indexing, however, such calculations are nowadays largely unnecessary as tables of leads and the gears required to cut them have been compiled, and are furnished as part of the universal milling machine's equipment.

Fig. 11 shows the set-up for cutting a spiral of 20-in. lead. Having selected the specified change-gears, then the next step in cutting a spiral is to determine the angle of spiral, so that the saddle of the machine can be swung to the correct angle.

If the angle of spiral is not given on the working drawing of the piece, it can be ascertained as follows:

$\frac{\text{Circumference of piece}}{\text{Lead of spiral}}$ = tan of angle of spiral. This can be converted to the required angle by referring to a table of natural tangents.

Having thus obtained the necessary angle of spiral, the saddle is swung to the correct graduation on its base.

Before swinging the saddle, however, the cutter should be set central to the piece being milled. When milling spirals, always make sure that the work-piece is correctly mounted on the mandrel, and that, in turn, is securely dogged to the headstock spindle.

After a cut has been made, it is best to drop the table, while bringing it back for another cut, and then return it to its previous position.

Indexing from one tooth to the next is done in the regular manner. For cutting left-hand spirals, the table is swung to the other side of zero, and an idler is introduced into the headstock gearing.

Gear-cutting.—Although not usually regarded as within the province of milling-machine work, gear-cutting can be performed quite accurately on the universal machine.

Spur Gears.—When cutting spur gears it is necessary to know the pitch, either diametral or circular, and the number of teeth required.

Milling-machine gear-cutters are usually made in sets of 8, numbering 1 to 8 for each pitch. Great care should be taken to see that the cutters are ground correctly, for an inaccurately formed gear-cutter will produce an inaccurate gear. The involute type of gear-cutter shown in Fig. 12 is the most common in use to-day, the teeth being ground on the front face as indicated.

Having ascertained the number of teeth, and selected the cutter that suits the required gear to be cut, we can proceed further. All gear-blanks must be measured carefully for diameter before commencing the job, and any undersized ones should be scrapped or turned down for smaller blanks. Over-sized blanks should be returned to the lathe for suitable adjustment.

It follows that if the diameter of the blank is incorrect to start with, serious inaccuracies will be present in the finished gear.

The next step is to see that the machine table, if a universal, is set at zero, and checked for parallelism to the column-face.

The gear-blank should then be mounted on a suitable mandrel, which is in turn securely dogged to the headstock spindle. Care should be taken, if a mandrel with a nut and collars is used, that the mandrel does not spring when the nut is tightened up. A dial indicator should be passed over the gear-blank preparatory to taking the first cut.

Before setting the cutter for depth, it must be set central with the gear-blank. This can be done by placing the blade of combination-square against one edge of the blank, and then bringing the blade against one side of the cutter, as in Fig. 13. The graduated sleeve on the transverse feed-screw is then set at zero. By a simple calculation, the blank can be brought central with the cutter, i.e. half the diameter of the blank less half the thickness of the cutter, the measurement being carried out by the graduated sleeve.

Once the cutter is set central, it only remains for the table to be elevated to the correct depth of cut, which remains constant throughout the whole operation. The work can now proceed, the teeth being indexed in the usual manner.

Spiral Gears.—The process of cutting spiral gears is similar to that of cutting ordinary spiral work.

The main thing to remember is to set the cutter central before swinging the saddle to the required angle of spiral. The change-gears to give the required lead are obtained as detailed previously.

Bevel Gears.—As the teeth of bevel gears vary in pitch from the large to the small end of the teeth, it is impossible to cut a perfect bevel gear with an ordinary involute cutter on a milling machine, so the teeth are finished to size at the large end and left small at the small end, this extra stock being removed later with a file.

Here are the data required for cutting bevel gears·

Pitch and number of teeth in each gear (the pitch is always measured at the large end of the teeth).

The thickness of teeth at each end.

The height of teeth above the pitch line at each end.

Cutting angle. (Or angle to set dividing head carrying the gear-blank.)

Correct cutter or cutters.

To find the correct cutter, measure the back-cone radius *ab* (as in Fig. 14); 2 *ab* × the diametral pitch gives us the number of teeth, for which the correct cutter is selected. If the mating bevel gears are alike, only one cutter is required; if one is larger than the other, two cutters may be required.

The next step is to determine the correct amount to set the cutter out of centre, so as to produce the correct form at the large end of the teeth. The following formulæ show how this can be obtained:

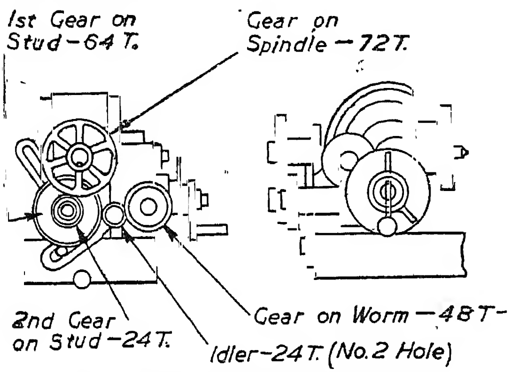

Fig. 10.—Dividing head geared for 319 divisions.

$$\text{Set-over} = \frac{Tc}{2} - \frac{\text{Table factor}}{\text{DP}}.$$

Tc = Thickness of the cutter at the pitch line.

DP = Diametral pitch of gear to be cut.

Table factor = Factor corresponding to the ratio of apex distance to length of face. (This factor can be obtained by consulting the table supplied by all leading makers, for use with their machines.)

Example.—Required to cut a bevel gear of 36 teeth, 8 in. diam. pitch, 45 degrees cone pitch angle and $1\frac{1}{2}$ in. face (F).

This gear calls for a No. 3 cutter and an apex distance of $5\frac{1}{4}$ in. Therefore:

$$\text{Ratio of apex to face} = \frac{5\frac{1}{4}}{1{\cdot}500}$$
$$= \frac{3{\cdot}50}{1} \text{ or } \frac{3\frac{1}{2}}{1}.$$

Consulting the table, we find that the factor corresponding to this ratio when using a No. 3 cutter is 0·271.

The next step is to measure the cutter at the pitch line. This is done by dividing 1·157 by the diametral pitch, which gives us the depth of space below pitch line, $s + f$. In our case it is $\frac{1{\cdot}157}{8} = 0{\cdot}1446$ in.

The cutter is then measured at the pitch line, and the thickness found to be 0·1265 in. Care should be taken over this dimension, as it will vary with different

cutters, and will also vary in the same cutter if it is one that necessitates regrinding on the sides of the teeth.

$$\text{Set-over} = \frac{0\cdot126}{2} - \frac{50\cdot271}{8} = 0\cdot0294 \text{ in.}$$

Having obtained the required amount of set-over, set the cutter central with the dividing-head spindle.

The bevel-gear blank is then mounted on a suitable adaptor and the dividing head tilted to the correct angle of bevel.

Set the sector arms on the index plate in a straight line to start with. Set graduated sleeve of transverse feed-screw at zero.

Mark the depth of both large and small ends of the tooth with a suitable scriber.

Set the cutter for depth and cut one or two preliminary centre cuts.

Now set the cutter off centre the required amount by moving the saddle. The gear-blank must now be rotated in the opposite direction to that of moving it off centre, until the cutter trims the entire sides of the approaching teeth.

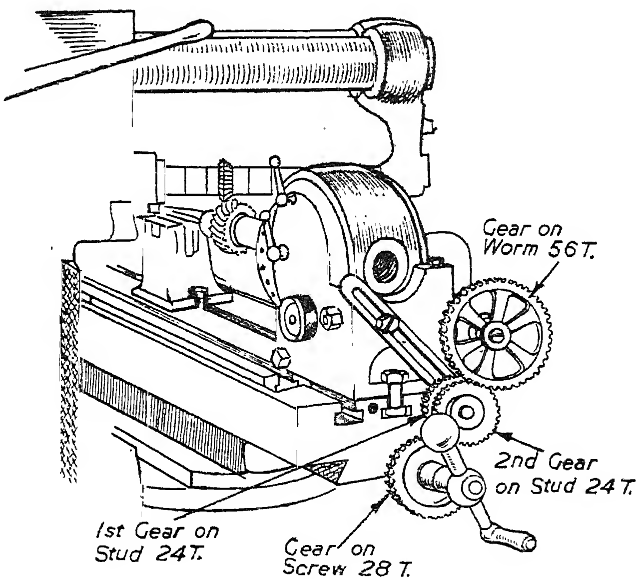

Fig. 11.—Set-up for cutting spiral of 20-in. lead.

This operation is repeated when the saddle is moved the opposite side of the centre of the preliminary cut.

Once the correct amount of set-over has been obtained, the work can be indexed right round, cutting first one side and then the other, thus doing away with the centre cuts.

As has been said before, the small ends of the teeth are touched up with a file after milling, thus bringing them as near correct as possible.

It is always wise to check up the tooth-form with a gear-tooth vernier before finally deciding to go right round the blank with the off-centre cuts.

Vices.—Perhaps the most common of all milling-machine attachments are the several different varieties of machine-vices that are probably considered essential

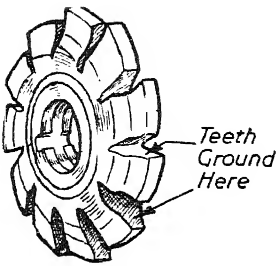

Fig. 12.—Involute-type gear-cutter.

to universal milling work. These vices can be classed as follows: plain, swivel, and universal.

The plain vice merely consists of a solidly cast base with appropriate slots cut in to take the clamping-down bolts, and a fixed and a movable jaw. This type of vice is used mainly on the lighter milling operations, or where the nature of the work calls for a secure, but not too strong, holding agent. The plain vice is also used extensively on drilling machines and surface-grinding machines.

The swivel vice is very similar to the plain type, but on this vice, as the name indicates, the top portion swivels on the graduated base to any desired angle. This vice can be used for a large variety of milling operations where an angular face has to be milled in relation to a square one without resetting the work. The vice is fitted with a pair of tenons on the base which locate the vice square with the machine when the vice is set at zero or 90 degrees.

The universal or toolmaker's vice can be used as an ordinary plain vice, or for work that calls for compound angles, and other irregular faces that have to be milled at one setting and without removing the work-piece.

The universal vice usually consists of a good heavy base, slotted to take the T-bolts, and a graduated portion upon which swivels a hinged knee, which can be elevated to any angle up to 90 degrees and securely clamped. On top of this is the vice proper, which also swivels to any desired angle, and can be clamped tight by two bolts.

All types of milling-machine vices should be set square with the machine before attempting to do any work. This can be done by running a dial indicator along the fixed jaw, as shown in Fig. 15. If a dial indicator is not available, another method is to place a try-square on the column-face and set the vice to the square accordingly. The dial-indicator method is best, however, and should always be used if really accurate work is required.

Vertical Milling Attachments.—There is rather a large range of these attachments available.

They are mainly used for vertical milling on horizontal machines. It is often the practice to do away with a vertical-spindle milling machine if a vertical milling attachment is available; so it will readily be seen that this attachment quickly converts a horizontal machine into a vertical-spindle one, thus proving its usefulness immediately.

One of the main values of the vertical attachment lies in the fact that it can be used on a plain machine in the operation of cutting spirals, the attachment taking the place of the swivel-table of the universal machine.

Also a great many jobs that call for a vertical-spindle machine of fairly heavy design can be done on a horizontal machine, such as end-milling, face-milling, cutting T-slots, drilling, boring, etc., when a heavy-duty type attachment is acquired.

As will be seen in Figs. 16–18, these attachments are securely located and bolted to the column-face and are driven direct from

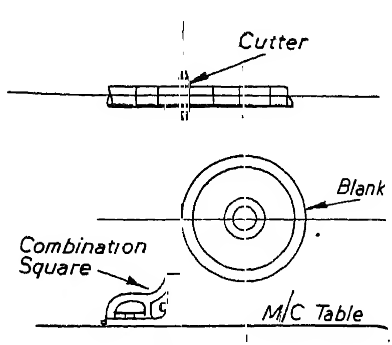

Fig. 13.—Setting gear-cutter central with blank.

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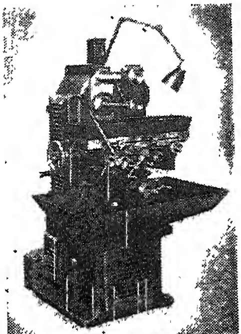
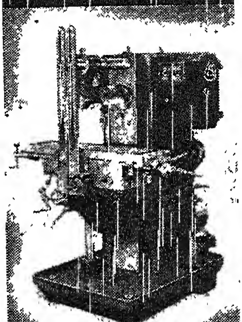
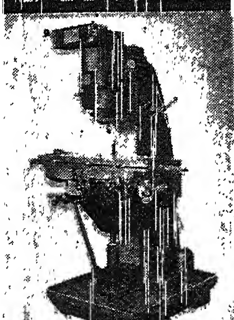
(2) "2 B" Horizontal Milling, Traverses 22″ × 7½″ × 18″
(3) "2 VE" Vertical Milling, Traverses 22″ × 7½″ × 18″
(4) "3" Horizontal Milling, Traverses 28″ × 8″ × 18″
(5) "4 V" Vertical Milling, Traverses, 39″ × 16″ × 16″



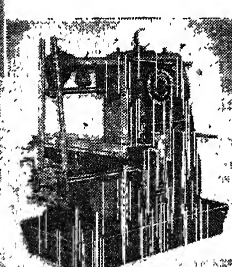
(1) '1 AM' MILLER



(2) '2 B' MILLER



(3) '2 VE' MILLER



(4) '3' MILLER

(5) MODEL 4V MILLER

the main spindle. Both light and heavy cuts can be taken, the drive being through anti-friction bearings. The attachments can be set at any angle between zero and 90 degrees for the milling of all types of angular work.

The high-speed vertical attachment is one that is much lighter in construction than usual, and is used extensively for production work where a rapid downward movement of the cutter is required. This attachment does not swivel, however, the spindle remaining vertical. Stops are often provided to facilitate the rapid milling of duplicate parts.

Compound Vertical Attachments. — These attachments are used mainly where angles in two planes are required. Their range of usefulness is therefore much greater than that of the ordinary vertical attachments described previously. This attachment is also bolted to the column, and carries two graduated scales for setting the spindle as shown in Fig. 18.

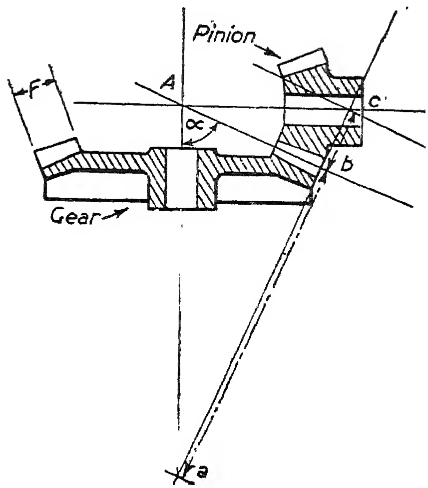


Fig. 14.—Bevel gears. Ab = Apex distance. ab = Back cone radius (gear). bc = Back cone radius (pinion). α = Centre angle.

Universal Vertical Attachments.—As the name implies, these attachment are fully universal in the setting of the spindle, and are particularly useful when used on a plain milling machine, for jobs that would ordinarily require a universal.

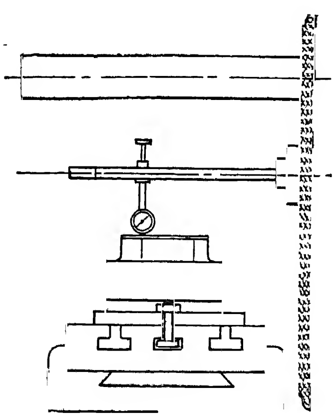


Fig. 15.—Setting vice with dial indicator.

Rotary Attachments.—For use in conjunction with vertical attachments, and particularly for use on vertical-spindle machines, the rotary attachment plays an important part in milling practice.

As shown in Fig. 19, the rotary attachment consists of a heavy base upon which is mounted a circular platen, graduated on the circumference in degrees and, in some cases, half-degrees. A hand-wheel gives adjustment of the platen through a worm and wheel. A graduated sleeve on the spindle of the worm gives accurate adjustment to five minutes of arc.

T-slots are cut in the platen to give easy clamping of the work-piece.

It may be said that the rotary attachment can be had in two types, hand and power feed. The hand-feed variety are mainly used on horizontal machines, while the power-feed attachment is used extensively on vertical-spindle machines.

For such jobs as milling radii

circular slots, irregular form milling, slotting internal teeth, etc., it will be seen that these attachments cover a large field.

For fairly light slotting operations on the milling machine we have the slotting attachment, which consists of a tool slide bolted to the column face and driven from the spindle by an adjustable crank. The slotting head can be swung to any angle on its graduated base, which further increases its value as a slotting agent.

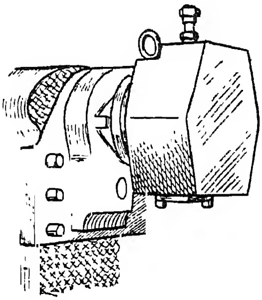


Fig. 16.—Vertical milling attachment.

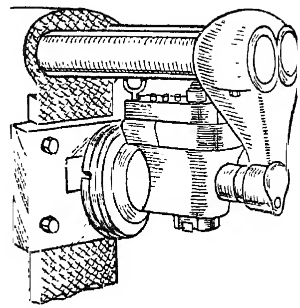


Fig. 17.—Vertical milling attachment—heavy-duty type.

For a great many tool-making operations such as slotting internal keyways, splining teeth, etc., this attachment proves invaluable.

For work of extreme accuracy, such as jig-boring holes in templates, jigs, fixtures, etc., the universal milling machine can be utilised quite well when fitted with a micrometer table-setting attachment. This attachment consists of a

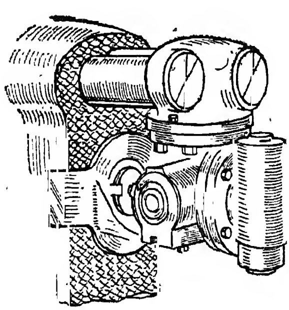


Fig. 18.—Compound vertical milling attachment.

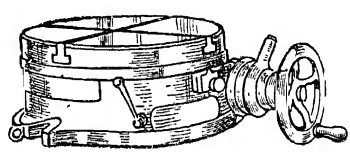


Fig. 19.—Rotary table (hand feed).

unit comprising a vee-support, and various measuring rods and slip gauges, and a dial indicator.

The work-piece is first located in the centre of the table, and the position of the first hole obtained. The vee-support is then clamped to the table guide, and a known length of measuring rod inserted against the table stop.

A dial indicator is then attached to the table side and the dial brought to zero

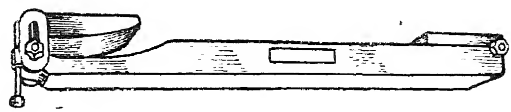


Fig. 20.—Tilting table.

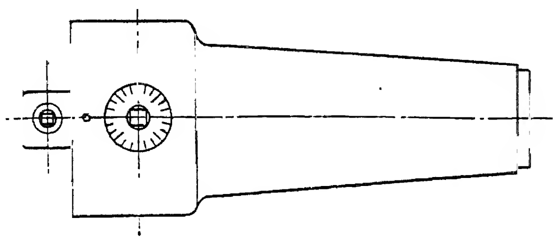


Fig. 21.—Boring head.

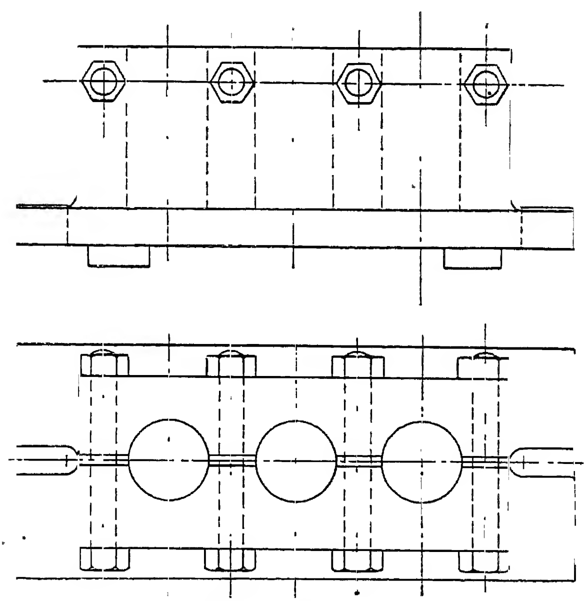


Fig. 22.—Plain fixture.

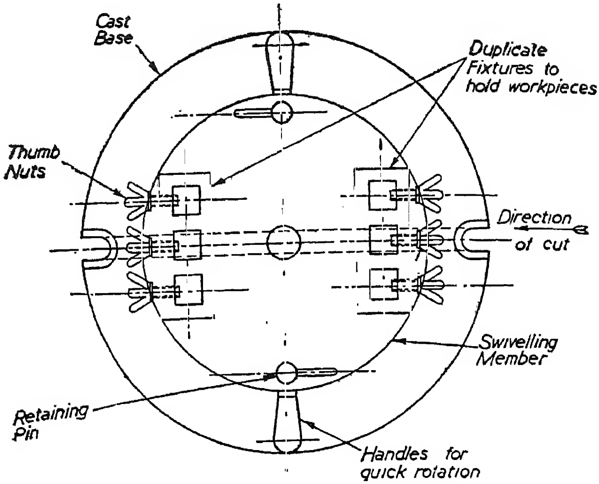


Fig. 23.—Circular fixture.

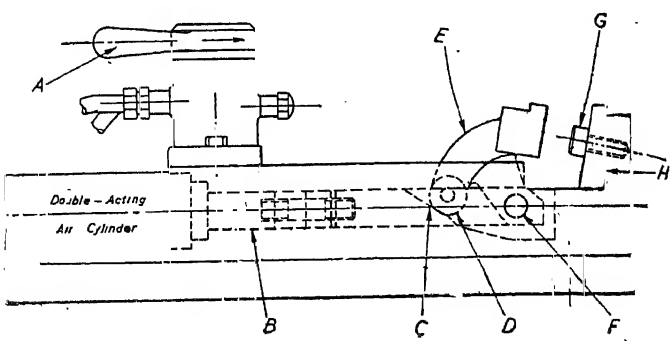


Fig. 24.—Air-operated fixture.

in conjunction with the measuring rod. To set the distance between holes the table is then moved and a new rod inserted to give the correct distance, the dial indicator again reading zero.

Micrometer-setting attachments may be used in this manner to set the table in both longitudinal and transverse directions.

Tilting Table.—A tilting table, or auxiliary table, comes in very useful when it is required to mill tapered work. It consists mainly of two base plates or feet, and a hinged platen that can be elevated by means of a thumbscrew. When the table has been raised to its required position, it is securely clamped by two bolts as shown (Fig. 20).

Finally we have an attachment known as a collet chuck. This consists of a tapered sleeve that fits into the spindle end of the machine, and various sizes of collets, for holding small drills, straight-shank end-mills, etc.

A cap screws over the end of the sleeve, closing the collet on the shank end of the tool in use.

Boring Head.—Although not considered to take the place of a boring machine, the universal miller can be adapted to do many types of boring jobs that would ordinarily require a special boring machine. To carry out accurate boring jobs, therefore, we have a boring head that fits into the horizontal spindle end, and is drawn into place by the draw-in bolt which runs through the spindle (Fig. 21).

The boring head consists of a rigidly constructed head with an adjustable piece into which the boring tool or cutter is inserted. This piece can be moved transversely to the axis of the boring head, and graduations on the outside give the amount of adjustment in thousandths of an inch.

Extremely accurate work can be done with this attachment, using single-point boring tools and the transverse traverse of the machine saddle.

Milling Jigs and Fixtures.—Fixtures are so designed that the work is adequately supported and clamped against the direction of cut. Provision is also made for easy loading and unloading of the work, and easy dispersal of chips and coolant.

Here, briefly, are short descriptions of a few of the more common types of fixtures that may be encountered in production milling.

Plain Fixtures.—These consist of a heavy split cast body, with holes of varying diameters bored in and fitted with bolts for clamping. These fixtures are used extensively for milling round work such as sockets, plugs, etc. In common with all types of fixtures, they have two tenons attached to the base for quick alignment in the T-slots of the machine table.

Circular Fixtures.—These are more complex than the plain variety, and are mainly used where rapid production times are essential.

Their general construction consists of a heavy rigid base upon which is mounted a round platen that can be rotated in a complete circle. Two stop-pins are provided for locking the platen in the operating position, and often handles are added to give easy rotation from one milling station to the next (Fig. 23).

On top of this platen is mounted the fixtures designed to hold the work-pieces. In this case the fixture is duplicated, so that while one work-piece is being milled, the operator can unload and reload the other fixture with another piece. Continuous milling can thus be carried out, the machine working all the time.

Swivelling Fixtures.—These are another type of circular fixture, and are used mostly for work that calls for indexing to various positions, such as in the milling of hexagons, irregular angular work, etc. For complicated pieces with many faces, these fixtures are invaluable on production work.

Air-operated Fixtures.—Comparatively new in the field of milling-machine jigs and fixtures are the type known as air fixtures. These are clamped and unclamped by the action of compressed air and a piston working against the clamping units of the fixture.

A simple form of air-operated fixture is shown in Fig. 24. This consists of a base-plate upon which is mounted two air-cylinders. When the lever A is thrown in the direction of the arrow, the piston B moves forward under pressure and carries the slide C into contact with a roller D, mounted in the movable jaw E. This causes the jaw to pivot about the fulcrum F, thus bringing it against the work-piece, which is located on suitable pegs G, screwed into the fixed jaw H.

By having two angles on the slide C, the jaw is definitely locked in position and cannot move if the air supply should fail.

To unclamp the fixture, the lever is thrown in the opposite direction, pulling the slide backwards and allowing the movable jaw to fall back for the insertion of of another piece.

It is important to make all air fixtures self-locking and not to rely on the air pressure alone to keep the work clamped, for if this is not adhered to the use of air fixtures becomes dangerous both to the operator and to the work and cutters being used.

Special Vice Jaws.—Use is often made of specially formed vice jaws to grip work of irregular character in the ordinary milling vice. These jaws consist simply of plates with suitable locations for the component, and are used in place of the plain jaws that are part of every machine vice. Sometimes a setting block for quick setting of the cutters is attached to the fixed jaw, which greatly facilitates production.

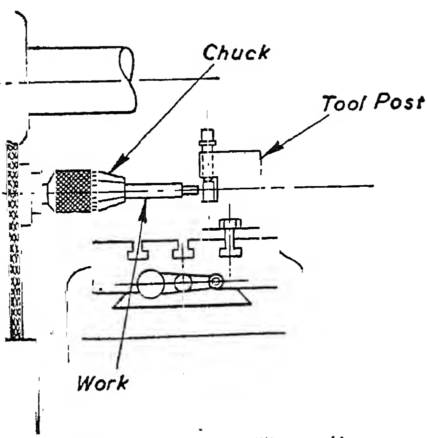


Fig. 25.—Turning on milling machine.

Lathe Work on a Milling Machine.—For these operations, which are performed more successfully on aluminium and other light alloys, there are two ways of setting the work.

For plain turning work, etc., the job is best held in a chuck, which is, in turn, held in the tapered spindle end of the machine. The necessary tools for the required operations are then bolted in a tool-box set on the machine table (Fig. 25).

The turning of the work is then performed by centring the tool with the work by elevating the knee, and depth of cut is regulated by the longitudinal adjustment of the table. The transverse movement of the saddle then carries the tool along the work.

Many such jobs can be done in this manner, such as the facing of round castings, recessing grooving, etc., a small face-plate taking the place of the chuck when doing irregular work.

Another method of turning on the milling machine is to mount the work on the arbor, if it is so possible, and run the turning tools along as described before.

Cutting Speed.—The cutter speeds, generally, are high for non-ferrous metals and low for ferrous metals. No definite speeds, however, can be given as these will depend upon whether the cutter is carbon or high-speed steel or tungsten carbide, its diameter, the nature of the material and the power of the machine.

As a general guide, the cutting speeds in feet per minute for roughing cuts, using carbon steel cutters, are:

Cast iron	40
Mild steel	60
Brass	75

and for finishing cuts a 25 per cent. increase on the above figures.

The rate of feed also depends upon the width and depth of cut, the kind of material machined, the quality of finish required, the rigidity of the work and the power of the machine. As a general rule, a relatively low cutting speed and a heavy feed are used for roughing, whilst for finishing the reverse is the case.

Sharpening Milling Cutters.—Use a medium soft-grade wheel, say 50 O, for carbon-steel cutters, and a 40 O for high-speed-steel cutters, using American wheels as standard of grit and grade, and the surface speed of these should be about 5,500 ft. per minute.

If the grinding wheel is 6 in. in diameter, then the revolutions per minute would be :

$$\frac{5,000}{3{\cdot}1416 \times 0{\cdot}5} = \frac{5,000}{1{\cdot}57} = 3,184 \text{ r.p.m.}$$

When sharpening spiral milling cutters, use a two-thousandth taper hardened-steel mandrel about 9 in. long with good centres. The cutter must fit both tight on the mandrel and between the pair of centres fitted to the work-table.

A dividing head is not used on this job ; the cutter is supported by a tooth rest adjusted in a position for indexing the teeth and giving the correct clearance angle. The illustration (Fig. 26) shows the setting when grinding with a cup wheel or a disc wheel. With the cup wheel the necessary angle for A is produced by setting the tooth support lower than the cutter- and grinding-wheel centres, whereas in the disc wheel the grinding-wheel centre is raised in relation to the cutter centres.

Use the centre height gauge of the work-table for gauging height of grinding-wheel centre, and from this the correct vertical setting can be made by the micro-feed hand-wheel.

If a cup wheel is used, set the face of the wheel 5 degrees from parallel position of cutter and in this position the actual grinding direction is downwards. Dress the wheel before use.

Set the stops on the work-table so that the cutter does not run off the tooth rest, practise for a few moments the spiral motion that will be necessary for grinding each tooth by holding the cutter close to the tooth rest with your left hand, and then, with your right hand, operate the work-table to right and left by the geared hand-wheel.

A very light cut should be taken for two reasons :

(*a*) To prevent the temper of cutter being drawn through lack of coolant, and

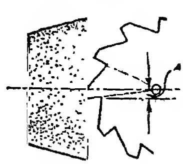
(*b*) To give one feed position for each complete revolution of the cutter to help to maintain concentricity of form.

When changing a grinding wheel or making a replacement for a worn one, check over the soundness by supporting the wheel through the bore with your finger and lightly tapping for possible cracks. If the wheel is unsound and unguarded whilst in motion you will ask for trouble and get it. See also that the new wheel has undamaged paper pads on each side, then mount between the steel flanges and tighten up moderately.

Remember that where the wheels are mounted at each end of the machine spindle, a left-hand screw thread secures the wheel on the left-hand side and the action through grinding tends to tighten the wheels in use.

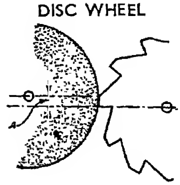
Adjusting the Slides.—The slides on the knee bracket, middle slide, and table should be kept adjusted

CUP WHEEL



Diameter of Cutter	5-degree Clearance Angle for Finishing Cut	7-degree Clearance Angle for Roughing Cut
in.	in.	in.
3	0·132	0·180
3½	0·154	0·210
4	0·176	0·240

DISC WHEEL



Diameter of Grinding Wheel	5-degree Clearance Angle for Finishing Cut	7-degree Clearance Angle for Roughing Cut
in.	in.	in.
4	$\frac{11}{64}$	$\frac{1}{4}$
5	$\frac{7}{32}$	$\frac{5}{16}$
6	$\frac{17}{64}$	$\frac{3}{8}$

Fig. 26.

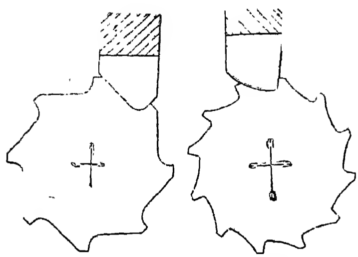


Fig. 27.—Reamer-fluting mills.

without side play and thoroughly lubricated. A properly adjusted machine will help to produce work free from chatter and also prevent cast-iron dust from damaging the working faces of the slides.

The slides should, of course, be locked up, but there are occasions when a down and slight side feed is necessary.

For this reason or to obviate backlash, a down-stroke milling machine has been invented in which the top slide or table inclines at an angle of about 15 degrees to the horizontal. The value of this is obvious.

Whilst on the subject of slide adjustment, it would be well to try the spindle for end play. You will soon discover that, if the cutter arbor is a "floating" one, the smallest amount of end play of the spindle will seriously upset the spacing of teeth of spur gearing that you may be cutting, whereas on surface work it would not be noticeable.

Alignment Tests of Machines and Work.—Alignment tests of the milling machine supplied to the purchaser by the manufacturer are a guarantee of its good workmanship. A typical test sheet for a new machine would read as follows:

Limits of accuracy in each of the following test positions is 0·001 in. in 12 in. when the knee is locked.

(*a*) Spindle parallel with top surface of knee.

(*b*) Spindle parallel with edge of knee.

(*c*) Surface of table and knee to be parallel.

(*d*) Test bar in the position of mandrel.

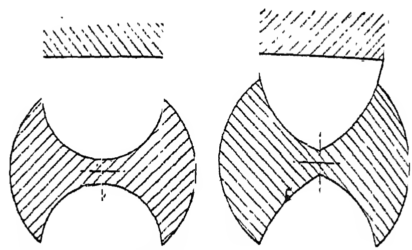


Fig. 28.—Cutters for grooving straight and twist drills.

Alignment tests for work set up on the table previous to milling are necessary and use should be made of the dial indicator. If you have the assistance of a modern milling machine and a dial-test indicator fitted to a scribing block, the test setting of work can be made from the edge of the work-table and from the surface. On the other hand, if the machine is a not-so-good one the indicator should be fitted to a stationary part of the machine and the dial adjusted to the inside jaw of a vice or work-piece to be set up for machining and traversed its full length. The readings on the work-table should be taken when the knee and middle slide are locked in position.

Setting the Milling Cutter.—As the micro-dial will be fitted to most milling machines, it is necessary to set the cutter so that the depth of cut can be correctly

Fig. 29.—Three representative tooth shapes. There is a straight-line back on types *A* and *B*, while the backs of the teeth are undercut in type *C*.

measured from the commencement. A very useful method of making a contact test between cutter and job is to feed the work up to the cutter, finally very gently, on to a thin ribbon of paper held in one hand ; a slight tugging of the paper will indicate what is happening, although the lifting of the knee when slide is tightened up will alter the original setting somewhat. The use of feeler and gauge blocks in some cases between cutter and job for setting purposes is unsatisfactory, because of the many inaccuracies due to the cutter arbor and cutters themselves not running true and the exact lowest position of a cutter tooth to be determined.

Coolant.—A coolant for the cutter is necessary whether for heavy production or light work, and a soluble oil for steel is generally used and this adds both to

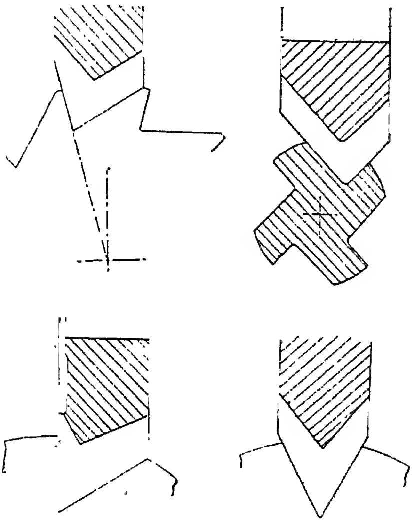


Fig. 30.—Standard angle cutters for fluting.

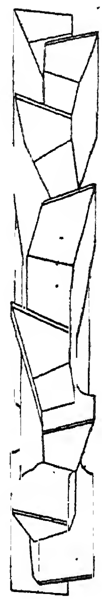


Fig. 31 (Right).—A staggered spiral-tooth mill for slotting.

the efficiency of the cutter and the finish of the work. Cast iron can be machined dry, but an application of light oils, such as paraffin, turpentine, etc., will assist the milling operation of some non-ferrous metals.

Micrometer Feed Dials (Micro-dials).—Find the value of the divisions of the micrometer feed dials before commencing operations on the milling machine. You may be tempted to measure the pitch of the screw and to count the divisions. This may bring you the answer. The feed screw may have a two-start thread, in which case you will have mistaken the lead for the pitch, giving you a double distance travelled for one turn of the handle or the geared screw of the knee, in which case a two to one bevel gearing is fitted and giving you half a turn of the screw for one of the handle in a vertical direction.

The correct method is to turn the handle of the slide and micro-dial clockwise until zero is reached, marking a contact place on the machine adjoining the slide with a lead pencil and then winding the handle through a known complete number of revolutions, again marking the machine to find the distance traversed.

If you know the distance traversed in one revolution of the handle, it is a simple matter to calculate the value of the units shown on the micro-dial.

Backlash has been mentioned previously. If when setting the machine you over-run the divisions on the dial, turn the handle backwards for one complete revolution and then come forward again.

Choice of Milling Cutter.—The considerations governing the choice of a milling cutter are:

(1) The number of teeth must be controlled by the horse-power available, and it is better to have too few than too many. If the work-piece will not withstand the power available, or the power is insufficient to use a conventional cutter efficiently, use fly cutters. It can also be arranged for a face mill to have several blades cutting to different depths or a form cutter to have several teeth operating on different parts of the form, thus obtaining the balanced load of a multi-blade cutter with the power consumption of a single-tooth cutter.

(2) The teeth should be of helical form wherever possible to ensure smooth action and good finish, and for the same reasons the heavier the cutter body the better. A flywheel often helps.

(3) The feed per tooth should not be less than 0·004 in.

(4) The surface speed must be right. Not too high for steel nor too low for carbide cutters. With form cutters, surface speeds may differ for different parts of the cutter, and it is better to run under speed for high-speed steel cutters, whereas with tungsten carbide it is better to run too fast than too slow.

(5) The machine and fixtures must be as rigid as possible.

Power Required for Milling Cutters

S = cutter speed in ft. per min.
F = feed in in. per min.
T = number of teeth in cutter.
R = r.p.m. of cutter.
= feed per tooth in inches.

D = diameter of cutter in inches.
K = cu. in. of stock removed by 1 h.p. in 1 min.
d = depth of cut in inches.
w = width of cut in inches.

(1) $\text{H.P.} = \dfrac{\text{No. of cu. in. of stock removed per minute}}{\text{K}}$.

(a) $= \dfrac{\text{F}dw}{\text{K}}$ But in 1 rev. the cutter advances $\dfrac{\text{F}}{\text{R}}$ in.

(b) Therefore $f = \dfrac{\text{F}}{\text{RT}}$ in. Thus $\text{H.P.} = \dfrac{f\text{RT}dw}{\text{K}}$. But $\text{S} = \dfrac{\pi\text{DR}}{12}$ or $\text{R} = \dfrac{12\text{S}}{\pi\text{D}}$.

Therefore feed per tooth $= \dfrac{\pi\text{DF}}{12\text{ST}} = f$; or $\text{F} = \dfrac{12\text{ST}f}{\pi\text{D}}$.

(c) Substituting this equation (1) we have now three alternative equations.

$$\text{H.P.} = 12\frac{\text{ST}fdw}{\pi\text{DK}} \qquad (c)$$

$$\text{H.P.} = \frac{f\text{RT}dw}{\text{K}} \qquad (b)$$

$$\text{H.P.} = \frac{\text{F}dw}{\text{K}} \qquad (a)$$

In using these the figure obtained for h.p. is that available at the cutter and the cutter is assumed to be sharp. Where the feed is taken from the same motor, due allowance must be made for the power required to move the table.

In the following examples 0·004 in. has been selected as the tooth loading since below this figure cutter wear increases rapidly without any corresponding advantages and at higher loads it is apt to be difficult to get a good finish.

For *steel* K = $\frac{3}{4}$ cu. in./h.p./min. (up to, say, 40 ton tensile).

(2) thus $\text{H.P.} = 5{\cdot}1\,\dfrac{(\text{ST}fdw)}{\text{D}}$

or using load/tooth of 0·004 in. we have $\text{H.P.} = \dfrac{0{\cdot}02\,(\text{ST}dw)}{\text{D}}$

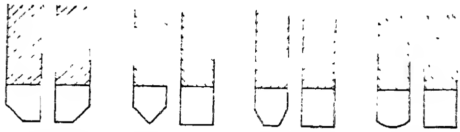


Fig. 32.—Some of the ways of varying alternate teeth in saws and slotting cutters to break the chips.

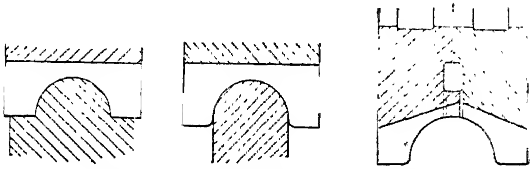


Fig. 33.—Representative types of concave mills.

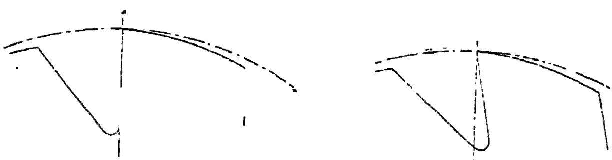


Fig. 34.—Tooth shapes of form cutters, radial and undercut.

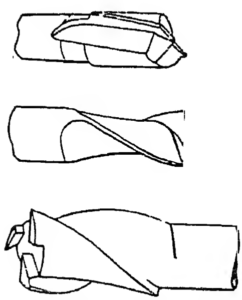


Fig. 35.—Two- and three-lip slotting mills.

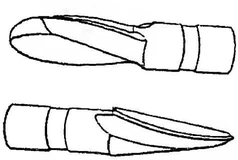


Fig. 36.—Strong cutters for die-sinking.

For *aluminium* alloys used in aircraft K is of the order of 2·5 cu. in./h.p./min.

$$(3)\quad \begin{cases} \text{so H.P.} = \dfrac{1{\cdot}53\ (STfwd)}{D} \\ \text{or if } 0{\cdot}004 \text{ in. tooth loading is chosen H.P.} = \dfrac{0{\cdot}006\ (STdw)}{D}. \end{cases}$$

For face milling the ratio $\frac{W}{D}$ should not be more than $\frac{3}{4}$.

This would give (2) H.P. = 0·015 (STd) for steel
or (3) H.P. = 0·0045 (STd) for aluminium.

It should be realised that K is arbitrary and dependent on the efficiency of the cutter. A blunt cutter or a carbide-tipped cutter running at too low a speed may require 40 per cent. extra h.p.

It must also be remembered that the weakness of the work-piece may prohibit the use of truly efficient cutterloading and that the most efficient loading from the viewpoint of h.p. or cutter life may not be the most economical cost per part machined.

Plunge-cut Milling.—In certain work such as the machining of a groove it is obvious that, quite apart from the time taken to traverse the length of the job, extra time is needed both before and after the cut for the cutter to approach the work-piece and to run out at the end of the cut. In many cases grooves do not have to fit anything at the bottom of the slot, and in such instances the sides of the groove are relied upon for location.

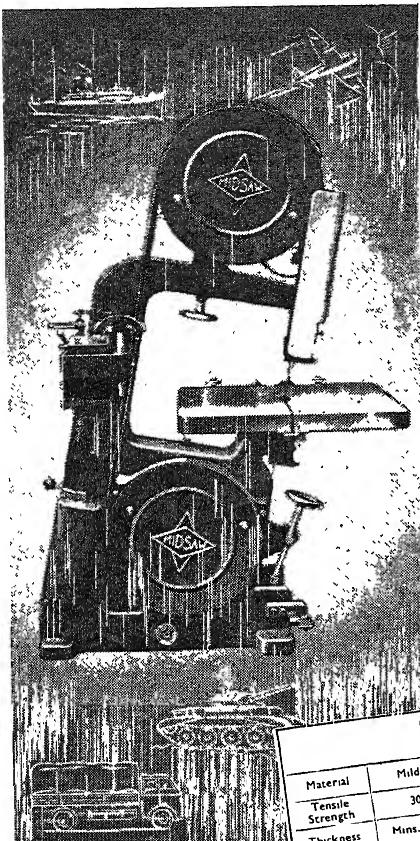
Frequently a base of curved contour can be used, and such a slot can be produced by plunge-cut milling. A cutter of suitable diameter, which is chosen in consideration with the amount of room available at the bottom of the slot to accommodate the radius, can be fed directly towards the work-piece. This feed can be accomplished in several ways. In-feeding is the most general, and in this the milling-table knee is raised under power feed.

Another method of plunge-cut milling makes use of an angle-plate which carries the work-piece and the table is thread longitudinally in the normal manner. This does not affect the normal speeds and feeds, as the surface feed at which a milling cutter is run depends upon the material from which the cutter is made, and the material of the work-piece. The table feeds depend upon the thickness of chip which must be produced for efficient metal removal. Sometimes the power available is not sufficient to drive the milling cutter at the correct feed, and either the work must be transferred to a larger machine, or the somewhat drastic method adopted of removing every alternate tooth from the cutter.

After the feed per tooth is settled, this should be multiplied by the number of teeth and the revolutions per minute to give the table feed. As this will give the same answer irrespective of the type of cutting taking place, i.e. up-cut, down-cut, or plunge-cut milling, it will be seen that a decrease in table-traverse stroke of, say, from 8 in. to ½ in., will mean a considerable saving in cutting time.

Some components can easily be modified to suit this desirable production technique. Screw heads sorted in this manner have a further advantage over screws plotted by the pass-under method, as the curvature at the base of the slot assists in retaining the screwdriver within the compass of the head of the screw during assembly processes. Advantage can be taken of feeding the screw towards the milling cutter along its axis by the use of a simple hinged type of jig.

Production can further be accelerated by arranging duplicate fixtures at each end of the table of the horizontal milling machine, both set up in relation to the same gang of cutters. By this means one fixture can be loaded whilst the other is in use. When the operation on the first work-piece is completed the operator has only to place the table quick traverse in action to bring a second work-piece into position for cutting, and then to let the feed carry on whilst he unloads and reloads the first fixture.



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CUTTING TIMES
Per Inch Length of cut

Material	Mild Steel		Carbon		Nickel Chrome Steel	
Tensile Strength	30 tons		45 tons		65 tons	
Thickness	Mins.	Secs	Mins.	Secs.	Mins	Secs
$\frac{3}{8}$ in		20		30		50
$\frac{3}{4}$ in		35		50	1	10
$1\frac{1}{2}$ in		50	1	15	2	50
2 in.	1	45	2	—	3	35
3 in	2	—	2	45	5	45
4 in	3	20	3	45	7	—

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CUTTING SPEEDS FOR MILLING CUTTERS

Feet per Minute	15	17·5	20	22·5	25	27·5	30	35	40	45	50	55
Diam. in In.	*Revolutions per Minute*											
$\frac{1}{16}$	917	1070	1222	1375	1528	1681	1883	2139	2445	2750	3056	3361
$\frac{1}{8}$	458	535	611	688	764	840	917	1070	1222	1375	1529	1681
$\frac{3}{16}$	306	357	407	458	509	560	611	713	815	917	1019	1120
$\frac{1}{4}$	229	267	306	344	382	420	458	535	611	688	764	840
$\frac{5}{16}$	183	214	244	275	306	336	367	428	489	550	611	672
$\frac{3}{8}$	153	178	204	229	255	280	306	357	407	458	509	560
$\frac{7}{16}$	131	153	175	196	218	240	262	306	349	393	437	480
$\frac{1}{2}$	115	134	153	172	191	210	229	267	306	344	382	420
$\frac{5}{8}$	91·7	107	122	138	153	168	183	214	244	275	306	336
$\frac{3}{4}$	76·4	89·1	102	115	127	140	153	178	204	229	255	280
$\frac{7}{8}$	65·5	76·4	87·3	98·2	109	120	131	153	175	196	218	240
1	57·3	66·8	76·4	85·9	95·5	105	115	134	153	172	191	210
$1\frac{1}{8}$	50·9	59·4	67·9	76·4	84·9	93·4	102	119	136	153	170	187
$1\frac{1}{4}$	45·8	53·5	61·1	68·8	76·4	84·0	91·7	107	122	138	153	168
$1\frac{3}{8}$	41·7	48·6	55·6	62·5	69·5	76·4	83·3	97·2	111	125	139	153
$1\frac{1}{2}$	38·2	44·6	50·9	57·3	63·7	70·0	76·4	89·1	102	115	127	140
$1\frac{5}{8}$	35·3	41·1	47·0	52·9	58·8	64·6	70·5	82·3	94·0	106	118	129
$1\frac{3}{4}$	32·7	38·2	43·7	49·1	54·6	60·0	65·5	76·4	87·3	98·2	109	120
$1\frac{7}{8}$	30·6	35·7	40·7	45·8	50·9	56·0	61·1	71·3	81·5	91·7	102	112
2	28·7	33·4	38·2	43·0	47·7	52·5	57·3	66·8	76·4	85·9	95·5	105
$2\frac{1}{4}$	25·5	29·7	34·0	38·2	42·4	46·7	50·9	59·4	67·9	76·4	84·9	93·4
$2\frac{1}{2}$	22·9	26·7	30·6	34·4	38·2	42·0	45·8	53·5	61·1	68·8	76·4	84·0
$2\frac{3}{4}$	20·8	24·3	27·8	31·3	34·7	38·2	41·7	48·6	55·6	62·5	69·5	76·4
3	19·1	22·3	25·5	28·6	31·8	35·0	38·2	44·6	50·9	57·3	63·7	70·0
$3\frac{1}{4}$	17·6	20·6	23·5	26·4	29·4	32·3	35·3	41·1	47·0	52·9	58·8	64·6
$3\frac{1}{2}$	16·4	19·1	21·8	24·5	27·3	30·0	32·7	38·2	43·7	49·1	54·6	60·0
$3\frac{3}{4}$	15·3	17·8	20·4	22·9	25·5	28·0	30·6	35·7	40·7	45·8	50·9	56·0
4	14·3	16·7	19·1	21·5	23·9	26·3	28·7	33·4	38·2	43·0	47·7	52·5
$4\frac{1}{2}$	12·7	14·9	17·0	19·1	21·2	23·3	25·5	29·7	34·0	38·2	42·4	46·7
5	11·5	13·4	15·3	17·2	19·1	21·0	22·9	26·7	30·6	34·4	38·2	42·0
$5\frac{1}{2}$	10·4	12·2	13·9	15·6	17·4	19·1	20·8	24·3	27·8	31·3	34·7	38·2
6	9·5	11·1	12·7	14·3	15·9	17·5	19·1	22·3	25·5	28·6	31·8	35·0
$6\frac{1}{2}$	8·8	10·3	11·8	13·2	14·7	16·2	17·6	20·6	23·5	26·4	29·4	32·3
7	8·2	9·5	10·9	12·3	13·6	15·0	16·4	19·1	21·8	24·5	27·3	30·0
$7\frac{1}{2}$	7·6	8·9	10·2	11·5	12·7	14·0	15·3	17·8	20·4	22·9	25·5	28·0
8	7·2	8·4	9·5	10·7	11·9	13·1	14·3	16·7	19·1	21·5	23·9	26·3
$8\frac{1}{2}$	6·7	7·9	9·0	10·1	11·2	12·4	13·5	15·7	18·0	20·2	22·5	24·7
9	6·4	7·4	8·5	9·5	10·6	11·7	12·7	14·9	17·0	19·1	21·2	23·3
$9\frac{1}{2}$	6·0	7·0	8·0	9·1	10·1	11·1	12·1	14·1	16·1	18·1	20·1	22·1
10	5·7	6·7	7·6	8·6	9·5	10·5	11·5	13·4	15·3	17·2	19·1	21·0
11	5·2	6·1	6·9	7·8	8·7	9·5	10·4	12·2	13·9	15·6	17·4	19·1
12	4·8	5·6	6·4	7·2	8·0	8·8	9·5	11·1	12·7	14·3	15·9	17·5
13	4·4	5·1	5·9	6·6	7·3	8·1	8·8	10·3	11·8	13·2	14·7	16·2
14	4·1	4·8	5·5	6·1	6·8	7·5	8·2	9·5	10·9	12·3	13·6	15·0
15	3·8	4·5	5·1	5·7	6·4	7·0	7·6	8·9	10·2	11·5	12·7	14·0
16	3·6	4·2	4·8	5·4	6·0	6·6	7·2	8·4	9·5	10·7	11·9	13·1
17	3·4	3·9	4·5	5·1	5·6	6·2	6·7	7·9	9·0	10·1	11·2	12·4
18	3·2	3·7	4·2	4·8	5·3	5·8	6·4	7·4	8·5	9·5	10·6	11·7

CUTTING SPEEDS FOR MILLING CUTTERS—*continued*

Feet per Minute	60	65	70	75	80	85	90	95	100	105	110	115
Diam. in In.						*Revolutions per Minute.*						
1/16	3667	3973	4278	4584	4889							
1/8	1833	1986	2139	2292	2445	2750	3056	3361	3667	3973	4278	4584
3/16	1222	1324	1426	1528	1630	1833	2037	2241	2445	2648	2852	3056
1/4	917	993	1070	1146	1222	1375	1528	1681	1833	1986	2139	2292
5/16	733	794	856	917	978	1100	1222	1345	1467	1589	1711	1883
3/8	611	662	713	764	815	917	1019	1120	1222	1324	1426	1528
7/16	524	568	611	655	698	786	873	960	1048	1135	1222	1310
1/2	458	497	535	573	611	688	764	840	917	993	1070	1146
5/8	367	397	428	458	489	550	611	672	733	794	856	917
3/4	306	331	357	382	407	458	509	560	611	662	713	764
7/8	262	284	306	327	349	393	437	480	524	568	611	655
1	229	248	267	287	306	344	382	420	458	497	535	573
1 1/8	204	221	238	255	272	306	340	373	497	441	475	509
1 1/4	183	199	214	229	244	275	306	336	367	397	428	458
1 3/8	167	181	194	208	222	250	278	306	333	361	389	417
1 1/2	153	166	178	191	204	229	255	280	306	331	357	382
1 5/8	141	153	165	176	188	112	235	259	282	306	329	353
1 3/4	131	142	153	164	175	196	218	240	262	284	306	327
1 7/8	122	132	143	153	163	183	204	224	244	265	285	306
2	115	124	134	143	153	172	191	210	229	248	267	287
2 1/4	102	110	119	127	136	153	170	187	204	221	238	255
2 1/2	91·7	99·3	107	115	122	138	153	168	183	199	214	229
2 3/4	83·3	90·3	97·2	104	111	125	139	153	167	181	194	208
3	76·4	82·8	89·1	95·5	102	115	127	140	153	166	178	191
3 1/4	70·5	76·4	82·3	88·2	94·0	106	118	129	141	153	165	176
3 1/2	65·5	70·9	76·4	81·9	87·3	98·2	109	120	131	142	153	164
3 3/4	61·1	66·2	71·3	76·4	81·5	91·7	102	112	122	132	143	153
4	57·3	62·1	66·8	71·6	76·4	85·9	95·5	105	115	124	134	143
4 1/2	50·9	55·2	59·4	63·6	67·9	76·4	84·9	93·4	102	110	119	127
5	45·8	49·7	53·5	57·3	61·1	68·8	76·4	84·0	91·7	99·3	107	115
5 1/2	41·7	45·1	48·6	52·1	55·6	62·5	69·5	76·4	83·3	90·3	97·2	104
6	38·2	41·4	44·6	47·8	50·9	57·3	63·7	70·0	76·4	82·8	89·1	95·5
6 1/2	35·3	38·2	44·1	44·1	47·0	52·9	58·8	64·6	70·5	76·4	82·3	88·2
7	32·7	35·5	38·2	40·9	43·7	49·1	54·6	60·0	65·5	70·9	76·4	81·9
7 1/2	30·6	33·1	35·7	38·2	40·7	45·8	50·9	56·0	61·1	66·2	71·3	76·4
8	28·7	31·0	33·4	35·8	38·2	43·0	47·7	52·5	57·3	62·1	66·8	71·6
8 1/2	27·0	29·2	31·5	33·7	36·0	40·4	44·9	49·4	53·9	58·4	62·9	67·4
9	25·5	27·6	29·7	31·8	34·0	38·2	42·4	46·7	50·9	55·2	59·4	63·6
9 1/2	24·1	26·1	28·2	30·2	32·2	36·2	40·2	44·2	48·3	52·3	56·3	60·3
10	22·9	24·8	26·7	28·7	30·6	34·4	38·2	42·0	45·8	49·7	53·5	57·3
11	20·8	22·6	24·3	26·0	27·8	31·3	34·7	38·2	41·7	45·1	48·6	52·1
12	19·1	20·7	22·3	23·9	25·5	28·6	31·8	35·0	38·2	41·4	44·6	47·8
13	17·6	19·1	20·6	22·0	23·5	26·4	29·4	32·3	35·3	38·2	41·1	44·1
14	16·4	17·7	19·1	20·5	21·8	24·5	27·3	30·0	32·7	35·5	38·2	40·9
15	15·3	16·6	17·8	19·1	20·4	22·9	25·5	28·0	30·6	33·1	35·7	38·2
16	14·3	15·5	16·7	17·9	19·1	21·5	23·9	26·3	28·7	31·0	33·4	35·8
17	13·5	14·6	15·7	16·9	18·0	20·2	22·5	24·7	27·0	29·2	31·5	33·7
18	12·7	13·8	14·9	15·9	17·0	19·1	21·2	23·3	25·5	27·6	29·7	31·8

TABLE FOR SELECTING CUTTER FOR MILLING SPIRAL GEARS

Angle of Spiral	*K*	*Angle of Spiral*	*K*	*Angle of Spiral*	*K*	*Angle of Spiral*	*K*
0° 0′	1·000	21° 0′	1·228	42° 0′	2·436	63° 0′	10·69
0° 30′	1·000	21° 30′	1·241	42° 30′	2·495	63° 30′	11·27
1° 0′	1·001	22° 0′	1·254	43° 0′	2·557	64° 0′	11·87
1° 30′	1·001	22° 30′	1·268	43° 30′	2·621	64° 30′	12·55
2° 0′	1·002	23° 0′	1·282	44° 0′	2·687	65° 0′	13·25
2° 30′	1·003	23° 30′	1·297	44° 30′	2·756	65° 30′	14·03
3° 0′	1·004	24° 0′	1·312	45° 0′	2·828	66° 0′	14·86
3° 30′	1·005	24° 30′	1·328	45° 30′	2·902	66° 30′	15·80
4° 0′	1·007	25° 0′	1·344	46° 0′	2·983	67° 0′	16·76
4° 30′	1·009	25° 30′	1·360	46° 30′	3·066	67° 30′	17·85
5° 0′	1·011	26° 0′	1·377	47° 0′	3·152	68° 0′	18·98
5° 30′	1·013	26° 30′	1·395	47° 30′	3·242	68° 30′	20·33
6° 0′	1·016	27° 0′	1·414	48° 0′	3·336	69° 0′	21·72
6° 30′	1·019	27° 30′	1·434	48° 30′	3·436	69° 30′	23·33
7° 0′	1·022	28° 0′	1·454	49° 0′	3·540	70° 0′	25·00
7° 30′	1·026	28° 30′	1·474	49° 30′	3·650	70° 30′	26·97
8° 0′	1·030	29° 0′	1·495	50° 0′	3·767	71° 0′	28·97
8° 30′	1·034	29° 30′	1·517	50° 30′	3·887	71° 30′	31·40
9° 0′	1·038	30° 0′	1·540	51° 0′	4·012	72° 0′	33·88
9° 30′	1·042	30° 30′	1·563	51° 30′	4·144	72° 30′	36·92
10° 0′	1·047	31° 0′	1·588	52° 0′	4·284	73° 0′	40·00
10° 30′	1·052	31° 30′	1·613	52° 30′	4·433	73° 30′	43·88
11° 0′	1·057	32° 0′	1·640	53° 0′	4·586	74° 0′	47·79
11° 30′	1·062	32° 30′	1·667	53° 30′	4·752	74° 30′	54·72
12° 0′	1·068	33° 0′	1·695	54° 0′	4·925	75° 0′	57·68
12° 30′	1·074	33° 30′	1·724	54° 30′	5·101	75° 30′	64·15
13° 0′	1·080	34° 0′	1·755	55° 0′	5·295	76° 0′	70·65
13° 30′	1·087	34° 30′	1·787	55° 30′	5·497	76° 30′	79·20
14° 0′	1·094	35° 0′	1·819	56° 0′	5·710	77° 0′	87·78
14° 30′	1·102	35° 30′	1·853	56° 30′	5·940	77° 30′	99·50
15° 0′	1·110	36° 0′	1·889	57° 0′	6·190	78° 0′	111·3
15° 30′	1·118	36° 30′	1·926	57° 30′	6·435	79° 0′	144·0
16° 0′	1·127	37° 0′	1·963	58° 0′	6·720	80° 0′	191·2
16° 30′	1·136	37° 30′	2·003	58° 30′	7·010	81° 0′	261·4
17° 0′	1·145	38° 0′	2·044	59° 0′	7·321	82° 0′	370·6
17° 30′	1·154	38° 30′	2·086	59° 30′	7·650	83° 0′	552·1
18° 0′	1·163	39° 0′	2·130	60° 0′	8·000	84° 0′	876·4
18° 30′	1·172	39° 30′	2·176	60° 30′	8·380	85° 0′	1509·0
19° 0′	1·182	40° 0′	2·225	61° 0′	8·780	86° 0′	2940·0
19° 30′	1·193	40° 30′	2·275	61° 30′	9·209	87° 0′	6990·0
20° 0′	1·204	41° 0′	2·326	62° 0′	9·658	—	—
20° 30′	1·216	41° 30′	2·380	62° 30′	10·160	—	—

Example.—Angle of spiral = 30 degrees; number of teeth in spiral gear = 18.

Factor *K* for 30 degrees, as found from the table, equals 1·540. Then, number of teeth for which to select the cutter = 18 × 1·540 = 28, approximately. Hence, use spur gear cutter for 28 teeth, or cutter No. 4.

Cutter Design.—Cutters (tungsten-carbide-tipped) should be robustly constructed with few teeth compared with conventional high-speed steel cutters. The body of the cutter should be heavy to impart flywheel action where possible. The two main types of cutters in use are built-up cutters and Meehanite body cutters.

Built-up Cutters.—These consist of shanks equipped with carbide tips fixed to the cutter body by wedges or screws in the same manner as inserted blades are fitted to built-up high-speed steel cutters.

Meehanite Bodied Cutters.—This type of cutter has tungsten-carbide tips brazed directly to cast Meehanite bodies.

This is a good system of construction, as the Meehanite gives a "cushioning" action to the tips, thus preventing breakage.

Brazing of Tips.—Tips should be brazed to the shanks or bodies of the cutters, using the minimum of brazing medium. The seating which is to receive the tip should be carefully prepared, preferably by grinding. The part of the tip in contact with the seating should also be well prepared to ensure good support for the tip.

Feed per Tooth.—Feed per tooth should never be less than 0·004 in., and can be increased to 0·010 in. where horse-power and machine conditions permit. As a general guide to operating conditions the following points will be helpful:

Tooth wears at edge—feed per tooth too small.

Excessive cratering—feed per tooth too large.

Excessive cratering can also be caused by excessive vibration in the machine or the spindle, or both. This can be overcome by (*a*) rigid fixtures, (*b*) table guides to be reconditioned, (*c*) spindle bearing adjustment, or (*d*) by the addition of a heavy flywheel on the spindle to cut down torsional vibration.

Speed and Feed Calculations.—The primary consideration in any application of carbide milling to steel is that of peripheral speed of the cutter. Suitable speeds are given in Table I.

The importance of feed per tooth has already been stressed; this, coupled with r.p.m. of the cutter (governed by peripheral speed to suit material in hand), necessarily limits the operating conditions to a choice of table speed dependent upon the number of teeth in the cutter, as given by the formula below:

Let f = Feed per tooth.
F = Table speed in inches per minute.
N = R.p.m. of cutter.
n = Number of teeth in cutter.

Then $F = N \times n \times f$. (I)

The stock removal in cubic inches per minute is limited by the horse-power available. Table I gives figures of cubic inches per minute removed by one horse-power, for various materials when using negative rake milling cutters at the appropriate speeds for those materials. These figures are for newly sharpened cutters, and the power required for the cutters will increase as cutter wear increases. A blunt cutter will probably take 20 per cent. more horse-power to drive it than a newly sharpened cutter, dependent upon condition of bluntness. A further point about horse-power figures is that they do not include the power required to drive the table, but represent horse-power required to drive the cutter only. This point must be remembered when making horse-power calculations for milling machines. The formula connecting cutting conditions and machine horse-power is given below:

Let V = Volume of metal removed in cubic inches per horse-power per minute.
w = Width of cut.
d = Depth of cut.
H = Horse-power available at cutter shaft.

Then $H \times V = F \times w \times d$. (II)

Combinations of this formula with that for table feed gives formulæ which can

be used for finding the number of teeth in a cutter for given conditions, horse-power required for a particular job, or depth of cut obtainable on a particular job, as follows :

Number of Teeth in Cutter

$$H \times V = N \times n \times f \times w \times d.$$

$$\text{Therefore } n = \frac{H \times V}{N \times f \times w \times d} \qquad \text{(III)}$$

Horse-power Required

From III.

$$H = \frac{N \times n \times f \times w \times d}{V}$$

Permissible Depth of Cut

From III.

$$d = \frac{H \times V}{N \times n \times f \times w}$$

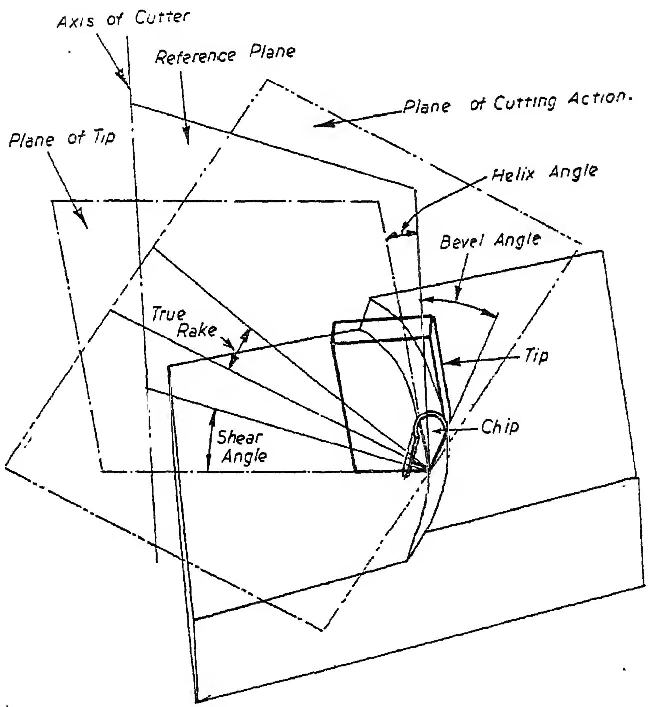

Fig. 1.—The "True Rake" is the important angle. This is the compound angle resultant from "Shear Angle," "Helix Angle" and "Bevel Angle" and lies in a plane at right angles to the tool face in the line of flow of the chip.

Nomenclature.—Fig. 2 illustrates the nomenclature used in milling practice.

Radial Rake (sometimes known as Cutting Angle or Cutting Rake or Shear): The angle that the tooth makes with the radius drawn from the point of the tooth to the centre of the cutter.

Axial Rake (or Helix Angle): The angle that the tooth edge makes with the axis.

Bevel Angle: This is the angle at which the teeth are ground back relative to the axis of the cutter (see Fig. 2).

True Rake: The angle between the tool face and the surface of the work being cut taken at right angles to the plain of flow of the chip (see Fig. 1).

Chamfer: The angular face connecting the bevel angle with the face angle of the cutter.

Face Angle: The inward clearance given to the teeth of a face mill to prevent drag.

Primary Land: The land directly adjacent to the cutting edge, which is diamond apped.

Secondary Land: The land next to the primary land.

Clearance: The angle at which the body of the cutter is "backed off" away from the tip.

Sharpening Negative Rake Cutters.—This should always be undertaken by means of a diamond lap. Machine lapping is preferable to hand honing. The aim should be to produce a perfect flat surface and a perfect edge free from irregularities. The performance of the cutter depends, to a large extent, upon the accuracy and finish of the tool faces.

Diamond laps should be run at a peripheral speed of 4,500 ft. per minute. Rape oil and paraffin or any other thin lubricating oil should be applied to resinoid bonded laps. Metallic bonded laps should be flooded with a copious supply of water to which can be added soluble oil or soda to prevent the machine from rusting. No more than 0·0002 in. should be removed per pass of the lap.

Truth of Cutters.—Each tooth of the cutter should be checked by means of an indicator when sharpening, and total run-out should not exceed 0·0008 in.

When set-up on the milling machine the cutter should be checked by means of a clock indicator and total run-out should not exceed 0·001 in.

In order to assign reasons for the use of apparently wrong cutting angles it is necessary to consider the action that is taking place when a piece of metal is machined. Briefly, the action is as follows:

The tool encountering the metal to be cut sets up conditions of compressive stress which, in turn, set up conditions of shear stress. The highly stressed metal tends to escape from the stressed areas by plastic flow. The resultant movement of metal causes break-down according to the nature of the particular metal acted upon. The action which eventually takes place is termed chip-flow, and can be divided into three types:

(1) Dissociated chip—brittle materials.
(2) Continuous-flowing chip—ductile materials.
(3) Continuous-flowing chip with built-up edge—ductile materials.

With type-1 chip the stresses built up in the material cause little plastic flow at first, which is soon replaced by shear across a "shear plane." The resultant small particle is projected up the tool face. With materials such as "leaded brass," cast bronze, etc., this flies off as a spray. In materials such as cast iron the small "chips" stick together.

Type-2 chip is a case of pure plastic flow formed by continuous shearing action across the shear plane. The highly compressed layer of metal adjacent to the tool face is continually flowing with the chip in this instance, and gives rise to the highly polished face of such chips. This is the most desirable form of chip.

Type-3 chip is formed by a similar action to type-2 chip, but in this case the highly compressed layer of chip clings to the tool point and forms a "built-up edge." This grows until an unstable position is reached, when the built-up edge disintegrates, part of it travelling up the tool face, part being embedded in the work-piece. This type of chip flow is actually undesirable for carbide-tipped tools owing to the strain imposed on them during break-down of the built-up edge.

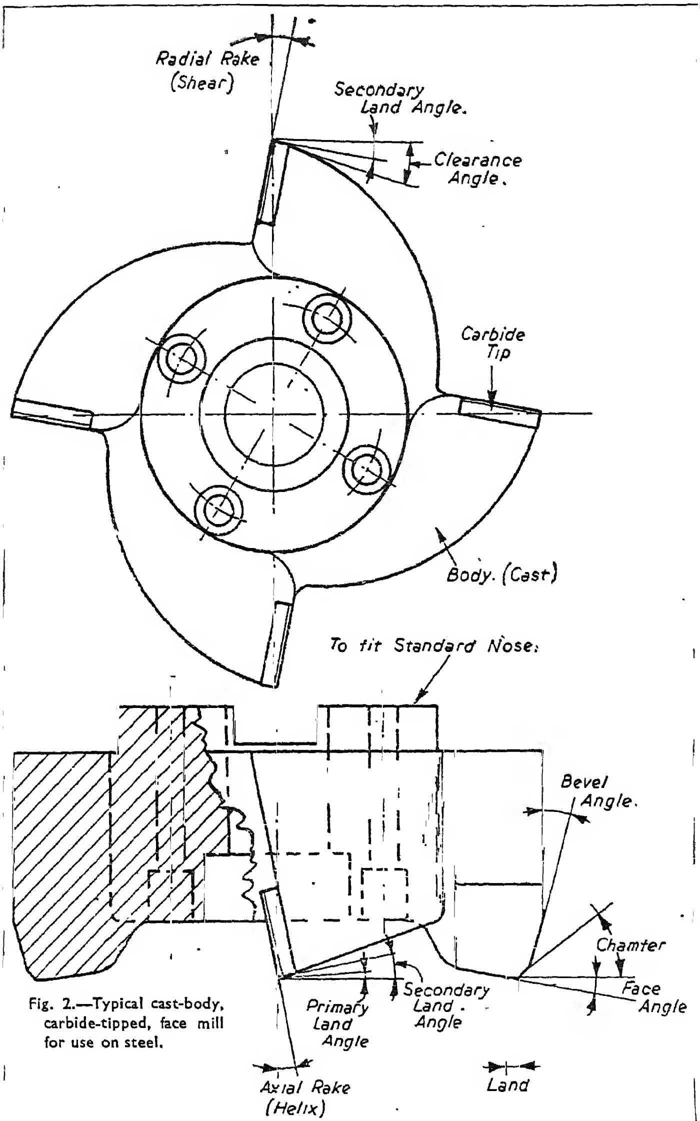

Fig. 2.—Typical cast-body, carbide-tipped, face mill for use on steel.

The type of chip formed depends not only upon the rake angle of the cutting edge, but also upon peripheral speed and the lubricant used. When milling with carbide-tipped cutters it is not practical to use a lubricant, as any such lubricant must be in contact with the tip all the time to prevent rapid fluctuation in temperature, which would harm the tip.

The rake used depends upon the nature of material used to form the cutting edge. Tungsten-carbide is weak in tension, but strong in compression, owing to the nature of its build-up.

TABLE I

Material	*Tensile Strength (tons/sq. in.)*	*Recommended Cutting Speed*	*Metal Removal (cu. in./h.p./min.)*
Mild steel	30	800	$\frac{3}{4}$
	35	750	$\frac{3}{4}$
Carbon steel	40	700	$\frac{7}{8}$
High-tensile steel ..	45	650	$\frac{7}{8}$
	50	550	$\frac{7}{8}$
	60	450	$\frac{7}{8}$
	70	400	$\frac{7}{8}$
Cast iron, grey ..	15 to 20	600	$\frac{7}{8}$
Meehanite	20 to 30	600	1

TABLE II
(See Fig. 2)

Material	*Tensile Strength (tons/sq. in.)*	*Radial Rake*	*Axial Rake*
Mild steel	30	$-5°$	$-10°$
	35	$-5°$	$-10°$
Carbon steel	40	$-7°$	$-10°$
High-tensile steel ..	45	$-7°$	$-10°$
	50	$-8°$	$-10°$
	60	$-10°$	$-10°$
	70	$-10°$	$-10°$
Cast iron	15 to 20	$+5°$	$-10°$
Meehanite	20 to 30	$+5°$	$-10°$

Grade of tip to be used:

Wimet	XX or X8
Kennametal	KH
Ardoloy	S200

or equivalent in other makes.

Index Table for Milling Machines

(40 turns of worm to 1 revolution of wormwheel)

Division	*Circle*	*Turns*	*Holes*
2	any	20	—
3	39	13	13
	33	13	11
	27	13	9
	21	13	7
	18	13	6
	15	13	5
4	any	10	—
5	any	8	—
6	39	6	26
	33	6	22
	27	6	18
	21	6	14
	18	6	12
	15	6	10
7	49	5	35
	21	5	15
8	any	5	—
9	27	4	12
	18	4	8
10	any	4	—
11	33	3	21
12	39	3	13
	33	3	11
	27	3	9
	21	3	7
	18	3	6
12	15	3	5
13	39	3	3
14	49	2	42
	21	2	18
15	39	2	26
	33	2	22
	27	2	18
	21	2	14
	18	2	12
	15	2	10
16	20	2	10
	18	2	9
	16	2	8
17	17	2	6

Division	*Circle*	*Turns*	*Holes*
18	27	2	6
	18	2	4
19	19	2	2
20	any	2	—
21	21	1	19
22	3	1	27
23	23	1	17
24	39	1	26
	33	1	22
	27	1	18
	21	1	14
	18	1	12
	15	1	10
25	20	1	12
26	39	1	21
27	27	1	13
28	49	1	21
	21	1	9
29	29	1	11
30	39	1	13
	33	1	11
	27	1	9
	21	1	7
	18	1	6
	15	1	5
31	31	1	9
32	20	1	5
	16	1	4
33	33	1	7
34	17	1	3
35	49	1	7
	21	1	3
36	27	1	3
	18	1	2
37	37	1	3
38	19	1	1
39	39	1	1
40	any	1	—
DEGREES			
1	18	—	2

General Rule.—A general rule which is not affected by the system of gears and/or pulleys employed—it applies whether the train is simple or compound—is that the product of the diameters (or the number of teeth in the case of gears) of the driving wheel and the number of revolutions per minute of the first driver is equal to the product of the diameters or the number of teeth of the driven wheels and the number of revolutions per minute of the last driven wheel.

In the workshop, calculations regarding speeds of machine countershafts, etc., are frequent, and the following formulæ apply:

$$\text{R.P.M. of driven pulley or gear} = \frac{\text{Diam. of driver} \times \text{R.P.M. of driver.}}{\text{Diam. of driven.}}$$

$$\text{Diam. of driven pulley or gear} = \frac{\text{Diam. of driver} \times \text{R.P.M. of driver.}}{\text{R.P.M. of driven.}}$$

$$\text{R.P.M. of driver pulley or gear} = \frac{\text{Diam. of driven} \times \text{R.P.M. of driven.}}{\text{Diam. of driver.}}$$

$$\text{Diam. of driver} = \frac{\text{Diam. of driven} \times \text{R.P.M. of driven.}}{\text{R.P.M. of driver.}}$$

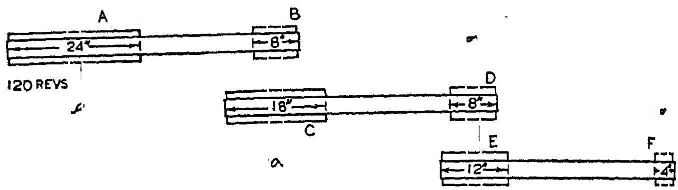

Fig. 1.—Example of triple belt drive, in which the main shaft revolves at 120 r.p.m. In this example $F = \frac{120 \times 24 \times 18 \times 12}{8 \times 8 \times 4} = 2{,}430$ r.p.m.

When three or more shafts are connected by belts the revolutions per minute of the first driver and the diameters of each driver are multiplied together and the product is divided by the diameter of the pulleys. The answer will indicate the number of revolutions per minute of the last driven pulley or gear.

Finding the Length of a Belt.—When the radius of the pulleys and the distance between two shafts are known, the following formula applies in which:

R = radius of the large pulley.
r = radius of the small pulley.
c = the centre distance.
L = the total length.

Open Belt—

$$L = \pi(R + r) + 2\sqrt{c^2 + (R - r)^2}.$$

For Equal Pulleys—

$$L = \pi(R + r) + 2c.$$

For Crossed Belt—

$$L = \pi(R + r) + 2\sqrt{c^2 + (R + r)^2}.$$

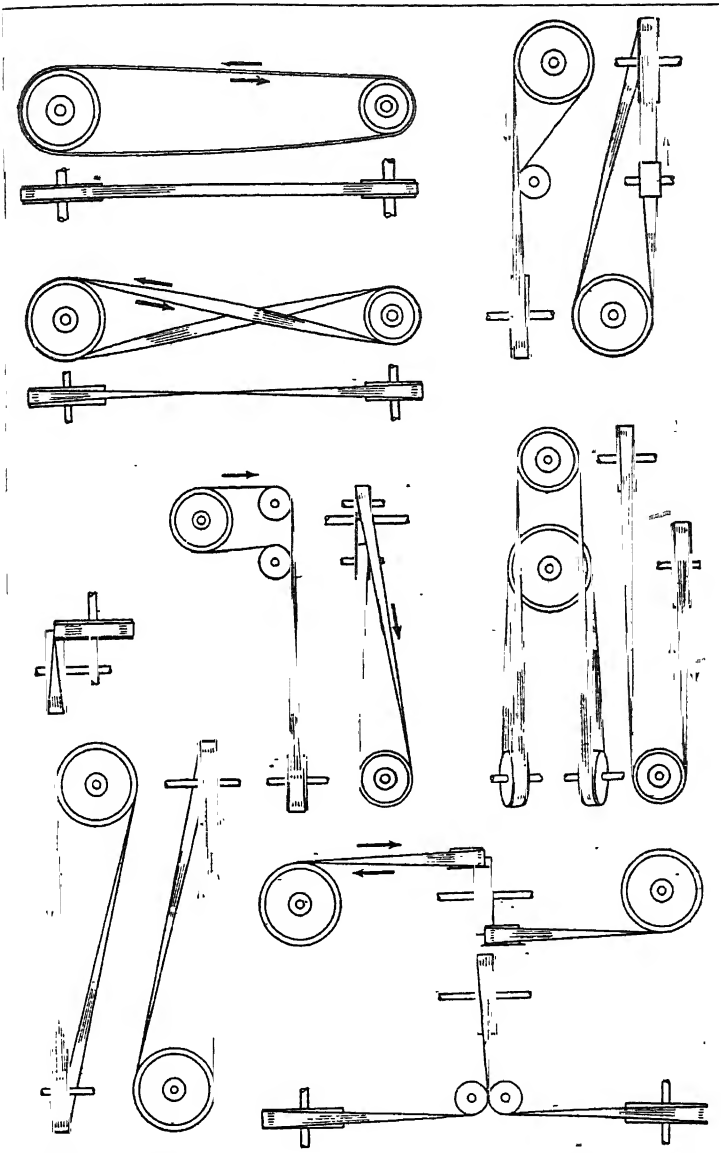

Fig. 2.—Various types of belt drive.

Belt Speed.—The usual velocity of belts varies from 1000 ft. to 1600 ft. per minute for the main driving belts in a workshop. The belts driving the machine tools vary in speed from 1000 ft. to 4000 ft. per minute.

Belt Tension.—Belt tension (working side) should not exceed 420 lb. per sq. in. when they have cemented and sewn joints, and 280 lb. per sq. in. when they are laced. Working tension is usually expressed per inch of width. The following table is a useful guide:

Single Belts ...	50 lb.
Light Double Belts	70 „
Heavy Double Belts	90 „
$\frac{3}{8}$ in. Link Belts	45 „
$\frac{1}{2}$ „ „ „	50 „
$\frac{5}{8}$ „ „ „	60 „
$\frac{3}{4}$ „ „ „	68 „
$\frac{7}{8}$ „ „ „	80 „
1 „ „ „	95 „

Proportions.—The pulley must always be wider than the belt and must have a slight crown, about $\frac{1}{4}$ in. to $\frac{1}{8}$ in. convexity usually being sufficient for pulleys up to 12 in. wide and proportionately greater for larger pulleys.

The ratio of diameters of mating pulleys should not exceed 6 to 1, and the distance apart should enable an arc of contact on the smaller pulley of at least 160 degrees.

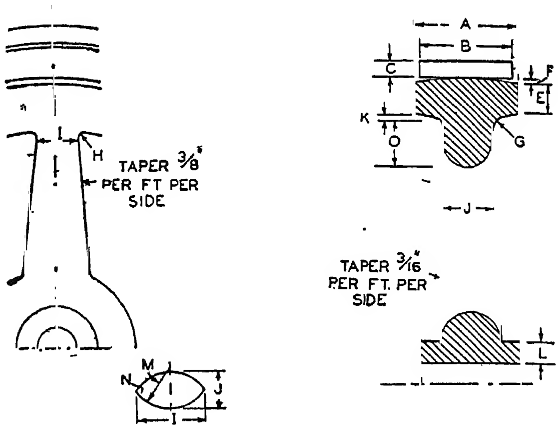

Fig. 3.—Pulley proportions.

Pulley Proportions (see Fig. 3)

A = width of face = B + $\frac{1}{4}$″ to $\frac{1}{2}$″.
B = width of belt.
C = thickness of belt.
D = diameter of pulley.
E = thickness of rim = ·005 × D + $\frac{1}{4}$″.
F = crown of face = $\frac{1}{4}$″ per 12″ face.
G = $\frac{1}{2}$ of J.

H = $\frac{1}{2}$ of I.
I = width of arm = (·04 × D) + $\frac{7}{8}$.
J = thickness of arm = $\frac{1}{2}$ of I.
K = taper of rim = $\frac{1}{2}$ of E.
L = metal around bore = $\frac{7}{16}$ of bore.
O = $\frac{1}{2}$ of I.

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Pulley Arms

I = width of arm.
J = thickness of arm = $\frac{1}{2}$ of I.
M = radius = $\frac{3}{4}$ of I.
N = radius = $\frac{1}{8}$ of I.

Number of Arms in Pulleys

6 in. to 24 in., 4 arms.
24 in. to 36 in., 5 arms.
36 in. to 96 in., 6 arms.
8 ft. to 16 ft., 8 arms.
16 ft. to 24 ft., 10 arms.

Relation of Belt Length to Pulley Size.—The formula connecting belt length, pulley sizes, and centres with sufficient accuracy for all practical purposes is :

$$L = \pi(R + r) + 2\sqrt{C^2 + (R - r)^2}$$

for an open belt, as given on p. 942.

Generally, design considerations fix the centres and the pulley radii R and r, so L can be calculated. Now let R_a and r_a be the radii of two further pulleys with V_a equal to the required velocity ratio, i.e. :

$$V_a = \frac{R_a}{r_a}.$$

Then,
$$r_a = \frac{y - \sqrt{y^2 - 4xz}}{2x} \qquad (1)$$
$$\text{and } R_a = V_a x r_a \qquad (2)$$
$$\text{where } x = \{\pi(V_a + 1)\}^2 + (V_a - 1)^2$$
$$y = 2\pi L(V_a + 1)$$
$$z \text{ and } a = L^2 - 4C^2$$

It should be noted that R_a may be greater or smaller than r_a, depending on the value of V_a.

This formula applies with reasonable accuracy to machine-tool drives for both flat and vee belts. The formula may be checked by assuming $R_a = r_a$, so giving $V_a = 1$. R_a and r_a then become equal to $\frac{L - 2C}{2\pi}$, or $L = 2\pi r_a + 2C$, which is correct for equal pulleys.

Tension.—In practice, the tension or pull of a belt is determined by the degree of friction or, in other words, the grip with which it bears on the pulley over which it operates. This degree of grip is mainly governed by the tightness of the belt, by its nature, condition, and thickness, and by the arc of contact which the belt makes with the pulleys.

Arc of Contact.—By the expression " arc of contact " is meant the proportion of the circumference of the pulley with which the belt actually makes contact during its movement around the pulley. Other factors being equal in a belt drive, the greater the arc of contact the better the grip of the belt on the pulley.

The driving side of a belt should, therefore, be the lower one, as in Fig. 4, since the slight sag of the upper side of the belt increases the arc of contact and thus heightens the efficiency of the drive. As will be seen from the same illustration, if the driving or pulling side of the belt is uppermost between the pulleys, the arc of contact between the belt and the pulleys will be reduced owing to the tendency of the lower side of the belt to sag away from the pulleys.

Crossed Belts.—Under normal conditions, the farther apart the pulleys are the better will be the grip of the belt on them. This rule applies particularly when the driving and the driven pulleys are of unequal sizes.

In cases in which it is impossible to provide a long belt drive, it is a good plan to cross the belt between the pulleys (Fig. 5). The practice of belt crossing as a general rule is not a good one, owing to the wear which is usually set up on the belt. Belts in excess of 8 in. wide should never be crossed in view of the wide rubbing area which would be set up at their crossing.

Another method of increasing the arcs of contact in a belt drive where the lower side of the belt is performing the drive is to have an idler pulley bearing on

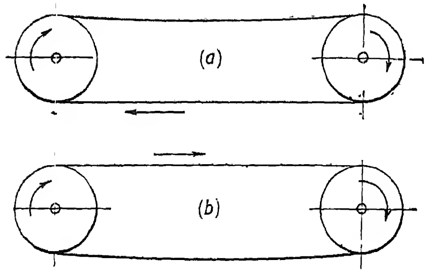


Fig. 4.—In diagram (a) the lower portion of the belt transmits the power and, since the upper part of the belt sags a little, the arcs of contact are increased. This makes for maximum efficiency in pulling power—other factors being equal. In (b) the above conditions are reversed. The upper half of the belt takes the drive. The lower half sags away and decreases the arcs of contact.

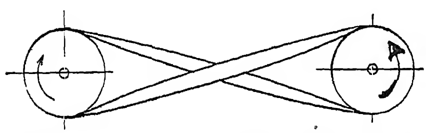


Fig. 5.—A crossed drive increases the arcs of contact between the belt and the pulleys, but it reverses the direction of the driven pulley.

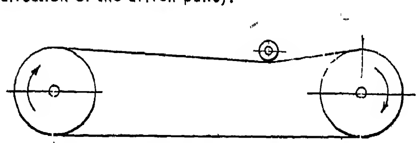


Fig. 6.—An idler pulley used to increase arcs of contact in a belt drive and to maintain even tension of the belt.

the upper side of the drive (Fig. 6), the idler pulley being situated as near to one of the working pulleys as possible.

Power Transmitted.—The amount of power which is transmitted by a belt drive can be calculated by multiplying together the pull of the belt and its velocity. Thus a belt travelling at the rate of 500 ft. per minute transmits double the power of one which moves at 250 ft. per minute.

The grip of a belt on a pulley is also affected by the actual condition of the belt. The side of the belt making contact with the pulley should be slightly soft and yielding, which condition is usually to be maintained by the judicious application of suitable belt-dressings. If the pulley side of the belt becomes dirty and hard, its surface will glaze and tend to slip.

Although the thicker belts are often stronger than the thinner ones, the latter are much the more flexible. Hence a thin belt should be used in preference to a thick one, particularly in cases in which the diameter of the larger pulley does not exceed 9 in. Thick belts, when moving around the pulley, are subjected on the pulley face to compressive forces and on the opposite face to stretching influences. Such belts are subjected to a continual sequence of stretching and squeezing strains which result in the permanent loss of "nature" of the belt.

The Pulley Crown.—The rims of pulleys are nearly always made very slightly convex or "humped" across the outer side. This increases the efficiency of the contact between pulley and belt, and it also lessens the tendency of the belt to come off the pulley. Usually, for pulleys up to about 6 in. wide, the degree of convexity across the outer pulley rim is from $\frac{1}{16}$ in. to $\frac{1}{8}$ in. If this degree of convexity is increased no further benefit is obtained, for in this case the load is thrown for the greater part on the centre of the belt, thereby deteriorating the belt and weakening its grip.

Belt Width and Strikers.—Belts should never be allowed to overlap the edges of their pulleys. The general rule is that pulleys should be from $\frac{1}{2}$ in. to $1\frac{1}{2}$ in. wider than the belt which runs over them. Strict adherence to this rule will protect the edges of a belt (which constitute its most vulnerable part) from injury.

When a belt drive incorporates the use of fast and loose pulleys for stopping and starting a piece of mechanism, see that the belt fork throws the belt on to the loose pulley completely clear of the fixed one, otherwise damage will be done to the edge of the belt.

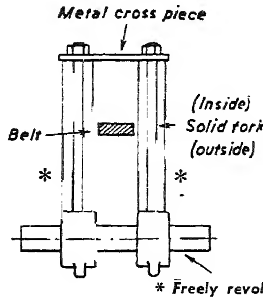


Fig. 7.—A type of belt-shifting fork which inflicts the minimum amount of wear on the sides of the belt.

When using a belt-shifting fork of the ordinary type, the edge of the belt must make frictional contact with the fork during the time of its being shifted from the one pulley to the other. This is not good for the belt. It is a good plan to employ a belt-shifting fork comprising the usual round forks over which lengths of suitable standard pipe have been fixed. The pipes are kept in place over the rods by a connecting end-plate (Fig. 7), and as the belt is shifted from one pulley to another the pipe making contact with the belt edge can rotate freely, considerably reducing the degree of friction between the belt and the fork.

A belt-shifting fork should operate the belt as near to the pulley as possible, since this makes for quicker and "sweeter" action. If the pulley is of large diameter, the forks should be made with a drop, for if they are made straight there will exist between the pulley and the fork a flexible length of belt which will tend to resist the action of the belt-shifting fork.

Belt Tensioning.—In some types of open-belt drives a belt-tensioning arrangement (known as the Lenix drive) is used. A jockey pulley riding on the slack side of the belt is used, the pulley being attached to a levered weight. By means of this principle it is possible to maintain any required degree of tension in the belt (Fig. 8).

Vertical "drives" should be avoided. A vertical drive is a drive which is taken from a shafting pulley to another pulley directly below it. Vertical drives are not efficient in that the belt, of its own weight, tends to drop off the lower pulley.

The Quarter-twist.—When two pulleys are situated at right angles to each other, use may be made of the quarter-twist belt drive, which is illustrated in Fig. 9. Here a strong flexible belt is needed.

The point at which the belt leaves one pulley must be in the central plane of the next pulley. In other words, one side of the belt must conform to the alignment of the dotted line shown in Fig. 9.

Leather Belts.—For flexibility, long life, and for sweet and efficient driving, leather belts have proved to be very satisfactory. Such belts are made in single, double, and triple thicknesses. Single-leather belting varies from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. in thickness. Double belts average about $\frac{3}{8}$ in. in thickness, whilst the triple belts exceed $\frac{1}{2}$ in.

The best-grade leather belts are made from the backbone centre of the hide, for the fibres of the material are more firmly knit in this area, and they tend to stretch less than in any other portion of the hide.

There is a difference of opinion as to which side of a leather belt should make actual contact with the pulleys, some engineers advocating the rougher side, while others favour the hair side (i.e. the outer side of the hide) on account of its greater hardness and smoothness. All things considered, it would appear that the outer (hair) side of the belt is the more efficient in contact with the pulley.

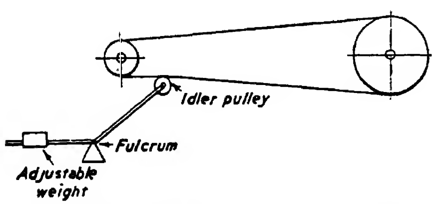


Fig. 8.—Belt-tensioning arrangement incorporating a lever-applied weight.

Textile Belts.—Textile belts are largely employed

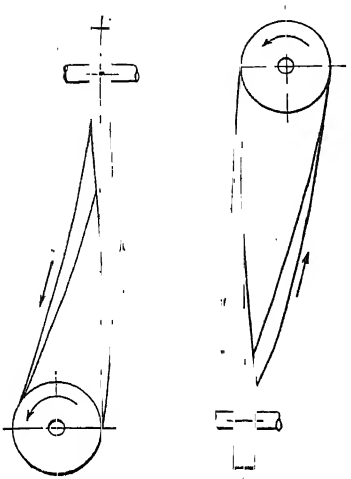


Fig. 9.—The vertical "quarter-twist" belt drive for transmitting motion between two pulleys at right angles to each other. The alignment indicated by the dotted line must in each case be secured.

in industry on account of their relative cheapness. They are composed of various mixtures of wool, cotton, hair, and other fibres impregnated with balata and other rubbery binders which weld the fibres together. "Balata belts," as they are often called, are more weatherproof than leather ones, and can therefore be used in outside situations. They are more liable to stretch, but they cannot be dressed with leather-belt dressings, since oil rots rubber. Such belts possess the decided advantage of being made in almost any length or thickness, and they are more or less immune to attack by acid and/or chemical fumes. They may also be made "endless," i.e. with their ends welded or vulcanised together.

Laminated and Steel Belts.—For short-centre drives, the laminated type of belting may be recommended. This comprises leather strands bound together by stitching. Such belts should not be used in situations in which grit is likely to be encountered.

Steel belts have been developed successfully in recent years, although they are not yet widely applied. A steel belt, owing to its great inherent strength, will transmit big power oads which could be dealt with by only a heavy leather belt. Owing to difficulties in fitting and adjustment, the steel belt has not attained the popularity which it deserves.

Joining a Belt.—When joining a belt, do not lay one end over the other and secure the two ends with rivets or stitches. No matter how the belt is joined, it is obvious that the joint represents the weakest and the least flexible portion of the belt. For average work on medium-power drives (particularly in the case of leather belts) one of the many types of "mechanical" belt-fasteners may be used with every satisfaction. Some of these fasteners are merely hooks or sets of teeth, clinched in position. Some comprise metal plates secured by nuts and bolts, whilst others employ a flexible joint. All such "mechanical" fasteners are less liable to pull through on leather belts than they are on textile belts.

An excellent way of fastening the ends of a leather belt is by use of the proper leather cement obtainable for such purposes. The edges of the belt are scarfed or skived (Fig. 10) so as to make an overlap of equal thickness to the thickness of the belt. They are then cemented and sometimes also stitched together. For the strongest possible lap joint of this type, a leather strip is stitched and cemented over the scarfed joint.

In dealing with belt joinings and fastenings, it should be remembered that no projection should be allowed on the side of the belt making contact with the pulleys. Time and care should be given to the making

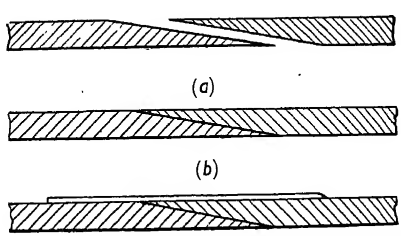


Fig. 10.—(a) The cemented "lap" joint for leather belts. (b) The "lap" joint reinforced by a strip of leather stitched in position above it.

of all joints in order to avoid the annoying " slap " caused by an unequal joint every time it goes over the smaller pulley.

Belt Slip.—When a belt persistently slips, and so loses power, the trouble may be due to the contracting side of the belt having become dirty and glazed. In such an instance, a washing-down with hot soda and water, followed by subsequent treatment with a suitable dressing, will usually remedy matters. If tightening-up a belt is found not to cure cases of slipping, it is very probable that the belt is being continually over-strained owing to overloading. In such an instance, the substitution of a heavier belt will cure the trouble. Usually increase in belt width is far preferable to increase in belt thickness.

Another way of curing a slipping belt drive is to use pulleys of greater diameter. This increases the speed of the belt and so lessens the tendency to slip.

A still further way to eliminate persistent slipping is to use a " compound " belt, i.e. one belt placed on top of another. In this instance, the outer belt, because of its weight, increases the grip of the inner belt and takes some of the load. Since it is not attached to the inner belt, the outer belt creeps slightly, so that the total flexibility of the compound drive is very high. The drive is akin to that which would be effected by the use of a very thick and strong belt having very much greater flexibility. Any type of old belt may be used as the outer belt in a compounded drive, but it is most essential that the outer belt should be perfectly free to creep over the inner one. Hence, no projecting belt fasteners must be present to prevent this creeping movement.

A belt, in addition to slipping, may persist in coming off its pulley. This, of course, may be due to badly aligned pulleys, but the trouble is commonly one of overloading. In such cases, the pulleys should be replaced by larger ones to increase the belt speed and thereby to decrease the load. A poor belt fastener is often an unsuspected cause of overloading, since a device of this kind allows knocking on the pulley and excessive wear and friction at the joint.

Excessive pulley camber will cause overloading of a belt, the camber causing a loss of grip on the sides of the pulley. The narrower the belt the worse the condition of overloading, since the belt is unduly stressed and a smaller amount of the belt surface makes gripping contact.

Belt Flap and Wobble.—What is known as belt " flap " is due to the belt obtaining a better grip on the pulley in some areas than it does in others. This is usually (faults of alignment omitted) due to the presence of excessive dirt, grit, or grease on the belt.

When a belt persistently moves to and fro across the pulley, this effect (known as " belt wobble ") may be due to the pulleys having unequal cambers or to the belt surface having become degraded and not of a uniform flatness. The cure in all such instances is obvious.

Rubber " V " Drives.—The installation of this class of drive presents an additional set of features not met with in the more common flat-belt drives. The matter of alignment is of vital importance in the case of this type, as the sides will wear very rapidly if the pulley sheaves permit side rubbing.

Two more points are that " V "-belt pulleys must be securely fixed to the shaft in order to prevent lateral " creep." In the case of a flat pulley a small degree of movement in a sideways direction may be tolerated, but in a " V " drive it will quickly ruin a belt or even a set of belts. The other point is in regard to length: as " V " belts are usually supplied in sets it will be readily appreciated that should one belt be the least shade tighter than its fellows, it will take all the drive itself, with disastrous results; hence it cannot be too strongly emphasised that only matched and measured sets should be used.

Length of Coil of Belting.—The rule to find the length of a rolled coil of belting, etc., is:

$$L = \frac{\pi n}{24} (D + d),$$

where L = Length of belt in feet.
$\pi = 3\frac{1}{7}$.
n = Number of turns and fractions of a turn in the coil.
D = Outside diameter of roll in inches.
d = Inside diameter of roll in inches.

As, however, $\frac{\pi}{24}$ is constant, the formula may be rewritten thus: $L = 0{\cdot}139n(D + d)$.

SURFACE BROACHING

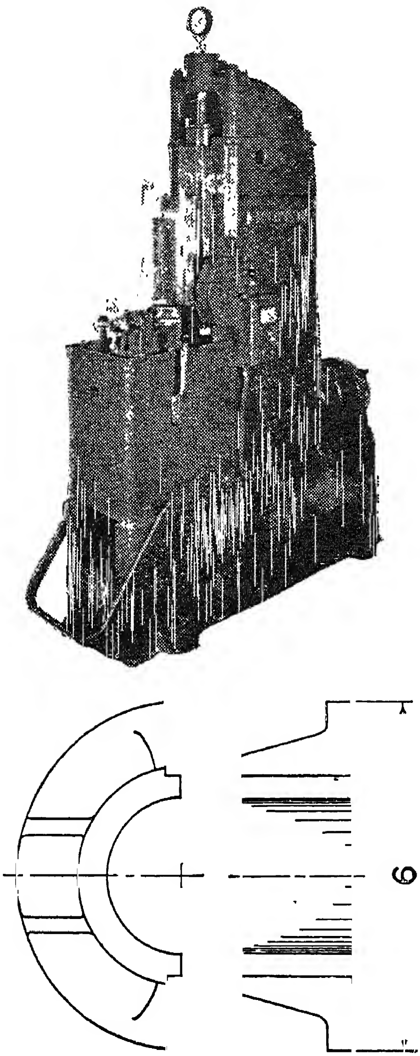


Fig. 1.—A Cincinnati single-ram vertical hydro-broach with fixed table. The part shown in the diagram is a bearing cap, and the lock-bearing surfaces have to be finish broached to width.

In recent years surface broaching has found many successful applications in relatively high-production industries as an alternative to other forms of machining. There are indications that the factors which have tended to this success are making the process commercially practicable for more moderate rates of output, and it is likely, therefore, that the next ten years will see increasing utilisation of this modern method of production.

Surface broaching is a process of machining flat or formed surfaces by means of multi-tooth tools, the cutting edges of which are progressively displaced in directions perpendicular to the path of the tool. As a rule, the relative motion between work and cutting tool is rectilinear.

The principal advantages of surface broaching are:

(1) High production.

(2) Low cost per piece (where volume of production makes initial cost economically feasible).

(3) One operation roughs and finishes.

(4) Good finish.

(5) Close tolerances.

(6) Infrequent tool-sharpening.

(7) Skilled labour not required.

The limiting factors in the successful application of surface broaching are:

(1) Work must be strong enough to stand broaching stresses set up.

(2) It must be possible to apply fixtures which will support the work firmly.

(3) Work must not have any obstruction in plane of surface to be broached.

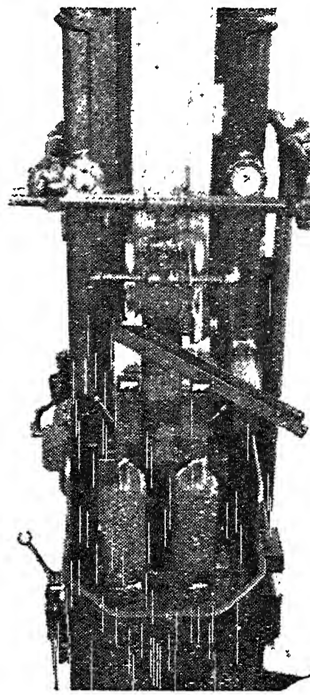
(4) Material to be surfaced must be within the range of machinability with edged tools.

(5) Depth of stock must be held within close limits.

Comparative Feed Rates.—The high productivity associated with surface broaching is due, in part, to the speed at which the cutter passes over the work. Feed rates used in milling steel forgings, for instance, are seldom higher, and generally lower, than about 8 in. per minute. Twenty-five feet per minute, on the other hand, is not unusual when surface broaching the same material. In this case the speed-up is $37\frac{1}{2}$ times the milling feed. Now, in either milling or broaching the distance travelled is equal to the length of cut plus the distance across the cutter. It is clear that the latter is considerably greater in broaching than in milling, and that the greater travel will tend to offset the increased speed. In spite of this factor, however, it will usually be found that the net result in favour of broaching is outstanding.

The high tool-life and infrequent tool sharpening associated with surface broaching are also due, in large measure, to the speed at which the cutter passes over the work. When it is realised that cut speeds in milling the same steel forgings may be in the region of 65 to 75 ft. per minute, the 25 ft. per minute of the surface broach appears slow and serves to explain the good cutter-life obtained. This property of high cutter-life established surface broaching as a trouble-free process requiring a minimum of supervision. It also accounts for the infrequent grinding required and, in spite of somewhat higher initial cost, in many instances explains the low ultimate tool cost per piece.

Principle of the Broaching Tool.—Since a broaching tool consists of a series of cutting teeth, it is possible to graduate their position with respect to the path of the broach so that a chip of any predetermined thickness is taken by each tooth. This possibility is usually exploited in such a way that the first portion of the broach takes roughing chips, after which the chip thickness is reduced on succeeding teeth, to obtain the required



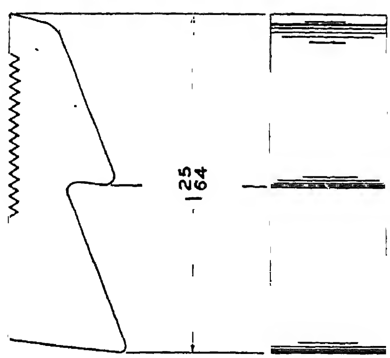


Fig. 2.—A No. 236 Cincinnati hydro-broach, with fixed table, equipped with automatic clamping and ejecting mechanism. It is set up for broaching the serrations in the striker for an automobile door, as shown in the sketch on the right.

finish. It will be observed that the finishing teeth, never coming into contact with the exterior scale, and being required to take only light finishing cuts of optimum thickness at low cutting speeds, are working under ideal conditions. This ability to combine with efficiency the functions of roughing and finishing in the same operation is unique to surface broaching and is another potent factor explaining its appeal.

The fact that it is only necessary to have one machine slide in a surface broach, added to the ease with which rigidity of structure is obtained, as well as the ideal conditions under which the finishing teeth work, explains why the accuracy obtainable by this method is higher than that reached by any other method of machining with edged tools.

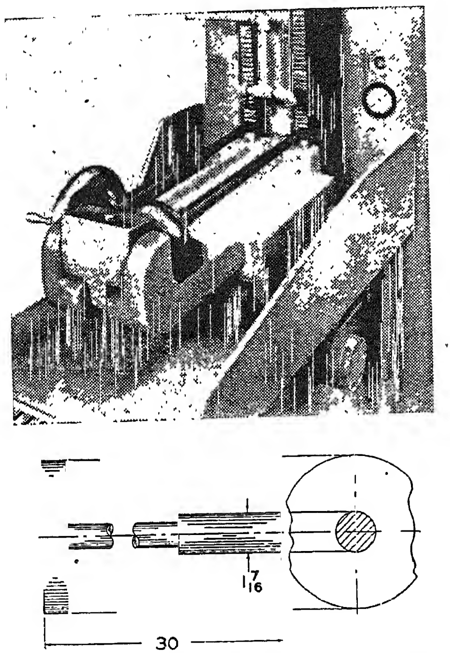


Fig. 3.—A Cincinnati vertical hydro-broach with receding table set up for broaching the small ends of motor-car rear-axle shafts.

Operation of the broach involves nothing more than the very simplest manipulation of machine controls, and, where this is not automatic, unloading and loading of the workpiece, making the process eminently suitable for operation by unskilled labour.

Types of Surface Broaches.—Like any other manufacturing process, surface broaching requires a suitable machine, tool, work-holding device, and work. Surface broaches now on the market fall into three main types:

(1) Vertical broaches, which incorporate either:

(*a*) Single-ram fixed table;

(*b*) Single-ram receding table;

(*c*) Double ram (duplex), with either swivelling or indexing tables.

(2) Horizontal broaches.

(3) Rotary broaches.

The three sub-classifications of vertical broach—(*a*), (*b*), and (*c*)—give ascending productivity. With a single-ram fixed-table vertical broach the ram stops at the bottom of the cutting stroke for unloading and again at the top of the return stroke for loading, and the operator is idle during both ram strokes. In spite of this fact, productivity will be found to be high in comparison with other methods of machining.

With a single-ram receding table vertical broach, the cycle may be either continuous or the ram may be automatically stopped at the top of the return stroke. Loading is carried out during the return stroke, and the operator is only idle during the actual cutting stroke. The cost of tooling required by this method is identical with that required for fixed table broaching. The only additional cost to be offset against the increased productivity is that of the receding table mechanism.

Duplex vertical broaches are customarily arranged so that the two rams reciprocate in opposite directions. An indexing table arrangement carries alternate fixtures to the broaching position in synchronism with the ram reversals.

Loading is carried out on whichever fixture is free, thus reducing idle time to a minimum and giving exceptionally high productivity.

Operation.—Power application may be either hydraulic or mechanical, although the former method is in most general use owing to the ease with which the high motive force may be applied and the speed thereof varied. It has also been found that better cutter-life is obtained owing to the cushioning effect of the hydraulic mechanism.

Horizontal surface broaches have been extensively applied to the surfacing of large cylinder heads, cylinder blocks, crank-cases, etc. For these purposes

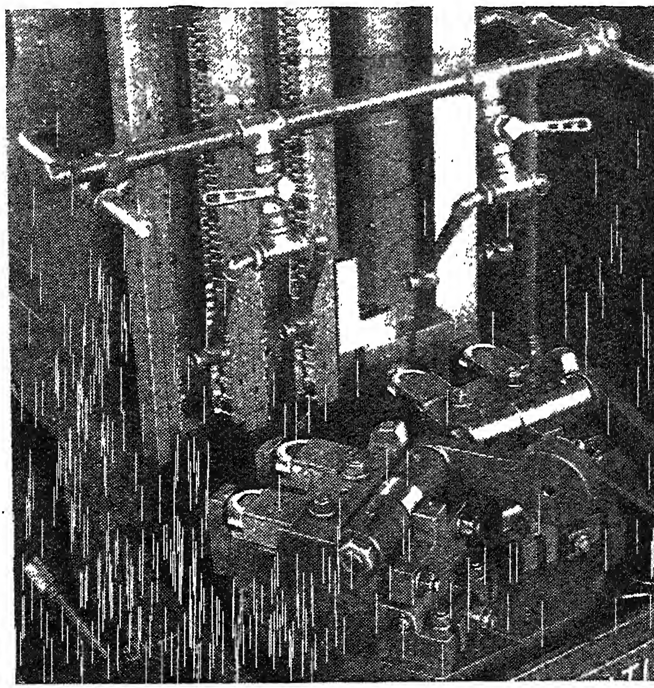


Fig. 4.—A 5-ton duplex vertical hydro-broach broaching the bolt-boss sides and ends of a connecting-rod cap.

they have been specially built with strokes greatly in excess of those given for vertical broaches, and in capacities of many tons.

Rotary surface broaches have also been specially constructed for specific high-production purposes with a central column carrying an annular broach, around which rotates an annular table on which are carried a number of work-holding fixtures. The operator stands at a fixed position and loads the fixtures as they pass him. The remainder of the circular travel is occupied in rough broaching, finish broaching and, finally, automatic ejection into a chute.

Broaching Fixtures.—The illustrations given depict typical applications on the three main types of surface broach. Fig. 1 shows a single-ram vertical hydro-broach of 1-ton, 18-in. stroke, finish-broaching the lock faces of a crank-shaft bearing cap. The material is cast iron, and the stock removal of 0·010 in.

is intended mainly for corrective purposes. Production is at the rate of 336 caps per hour.

Fig. 2 shows a 2-ton, 36-in. stroke, single-ram vertical hydro-broach with fixed table, equipped with automatic clamping and ejecting mechanism, broaching the serrations in a motor-car door-striker. The material is cold-rolled steel, the stock removal $\frac{1}{16}$ in., and the production 1,200 door-strikers per hour. All the operator has to do is to feed fresh pieces into each of the two hoppers shown; the machine automatically feeds these to the broaching position, clamps, broaches, and ejects them into the chute. A seat and footrest (not shown in the picture) are provided for the comfort of the operator.

Fig. 3 shows a 5-ton, 42-in. stroke, single-ram vertical hydro-broach, with receding table, broaching the small end of motor-car rear-axle shafts. The

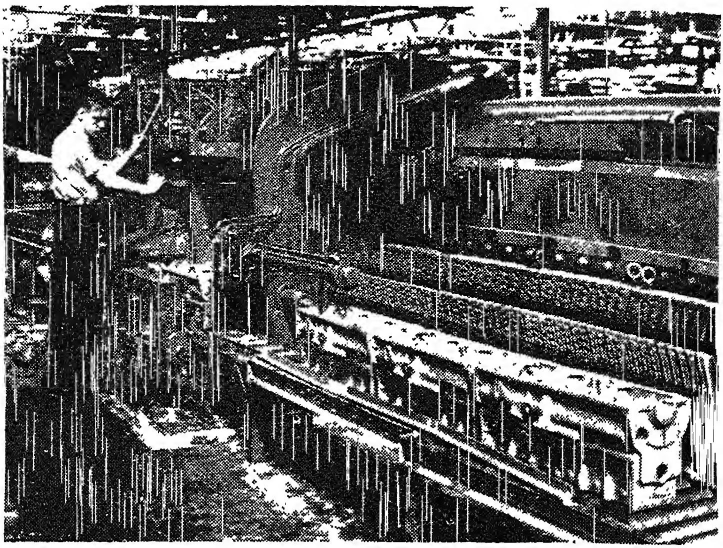


Fig. 5.—A double-acting horizontal hydro-broach arranged for surface broaching various faces on a motor-car cylinder block.

material is steel forging, the stock removal is $\frac{1}{4}$ in., and the production 356 shafts per hour.

Fig. 4 shows a 5-ton, 42-in. stroke, duplex vertical hydro-broach broaching the bolt boss sides and ends of a connecting-rod cap. The material is alloy-steel forging, the stock removal $\frac{1}{8}$ in., and the production 760 caps per hour. It will be observed that the right-hand ram is down, having just completed its working stroke. The left-hand fixture has been loaded and is ready to index forward, preparatory to the down stroke of the left-hand arm. Two caps are held in each of the two fixtures.

High Output.—Fig. 5 shows a powerful special double-acting horizontal hydro-broach, arranged for surface broaching the bottom, top, valve-chamber cover face, and distribution pad on a 6-cylinder motor-car block. The material is cast iron, stock removal $\frac{3}{16}$ in. maximum, and production is at the rate of 60 cylinder blocks per hour.

By providing a horizontal ram of sufficient width to carry two sets of broach teeth, one above the other and acting in opposite directions, practically continuous production is obtained, as follows: Two swinging cradle fixtures locate and clamp the block in two positions. The fixture at the right of the operator is

shown in the loading position, and holds the piece while the bottom surface is broached by the lower set of broaches, visible to the right of the picture. The second—left-hand—fixture can be observed under the operator's arms, and is in the "swung up" or broaching position. The broach teeth for the operations performed in this latter fixture are carried on the top half of the horizontal ram, and can be seen emerging from beneath the fixture-carrying frame. These operate with left-to-right ram travel. The broach teeth below these, and extending out to the right of the picture, machine the bottom of the block when in the right-hand fixture, and operate with right-to-left ram travel.

A special power-operated transfer cage is mounted on trunnions between the right-hand and left-hand fixtures, and serves to reverse the position of the block in its passage from the right-hand to the left-hand fixture. The transferring of work from the conveyor into and out of the two fixtures and transfer cage and on to the exit conveyor is all done by hand-controlled hydraulic power. Exceptionally good finish is obtained, and all surfaces are machined flat within 0·0003 in.

Broaching Applications and Methods.—Broaching is now used for many operations formerly done on the milling, planing, or shaping machine. Circular holes may be produced by broaching to finer limits than those obtainable by reaming. The process is also suitable for producing spline holes, annular gears, internal cams, square and polygonal holes, or any internal regular or irregular profile of constant section; even the holes in connecting rods for internal-combustion engines are now produced by this method, and the rifling of the helical grooves in the barrels of machine-guns are so produced. External broaching is employed for slotting castellated nuts, machine bevel pinions, rack teeth, and numerous other profiles and surfaces. Broaches are of two types—push and pull. Push broaches are forced through the work by pressure which places them in compression, and these are of necessity therefore quite short. This fact, together with the tendency to deviate from its path, has severely limited the application of the push broach, which is gradually being superseded by the pull broach. The pull broach is in tension while cutting and is limited in length only by the stroke of the machine on which it is to be used.

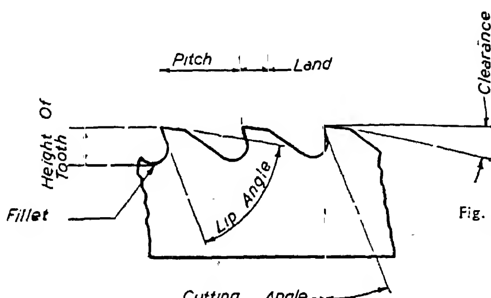


Fig. 6.—Broach tooth terminology.

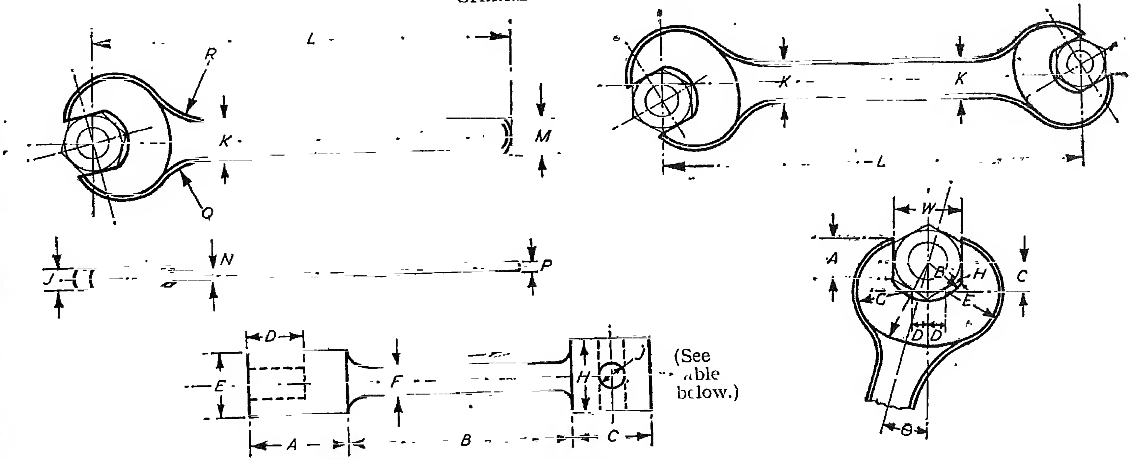
AVERAGE DEPTH OF CUT PER TOOTH

Material	*Circular*	*Spline*	*Rect-angular or Irregular*	*Keyway*
	in.	*in.*	*in.*	*in.*
White cast iron, steel, aluminium	0·002	0·0024	0 003	0·0035
Grey cast iron, brass	0·004	0·005	0·006	0·007
Bronze ..	0·006	0·008	0·015	0·020

BROACH TOOTH-CUTTING ANGLES

Material	*Cutting Angle*
	degrees
Bronze ..	0
Brass ..	2
Cast iron ..	3–6
Aluminium ..	6
Babbit metal	8
Cast steel ..	8–10
Mild steel ..	12–15
Copper ..	15

Spanner Proportions



Box Spanner Dimensions in Inches

Nut	A	B	C	D	E	F	H	J
$\frac{5}{8}$	$1\frac{1}{4}$	$3\frac{1}{2}$	1	$\frac{7}{8}$	$1\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{7}{16}$
$\frac{3}{4}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{1}{4}$	1	$1\frac{7}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$\frac{9}{16}$
$\frac{7}{8}$	$1\frac{3}{4}$	4	$1\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{4}$	1	$1\frac{1}{2}$	$\frac{11}{16}$
1	2	$4\frac{1}{2}$	2	$1\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{1}{4}$	2	$\frac{13}{16}$
$1\frac{1}{8}$	$2\frac{3}{8}$	5	$2\frac{1}{4}$	$1\frac{5}{8}$	$2\frac{3}{4}$	$1\frac{3}{8}$	$2\frac{1}{4}$	$\frac{15}{16}$
$1\frac{1}{4}$	$2\frac{5}{8}$	$5\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{3}{4}$	3	$1\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{1}{16}$
$1\frac{1}{2}$	3	$5\frac{1}{2}$	3	2	$3\frac{3}{4}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{3}{16}$

Dimensions of British Standard Spanners

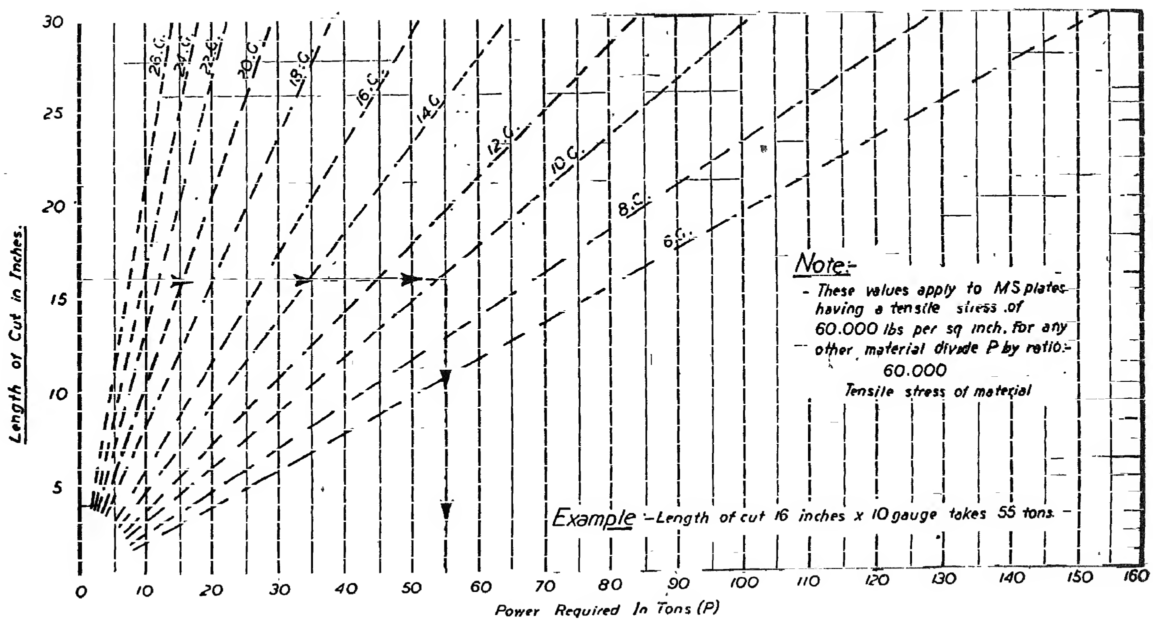
ALL DIMENSIONS ARE IN INCHES

B.S.I. Specification

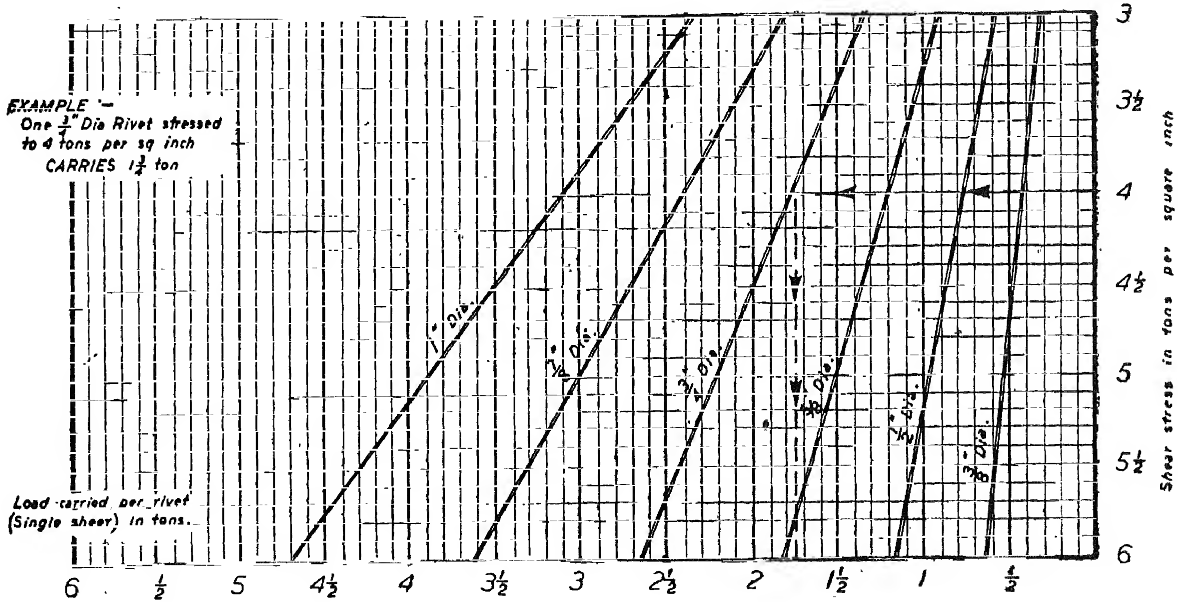
Dia. of Bolt				*Dimensions of Spanner*																
B.S.W.	B.S.F.	*Max.*	*Min.*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*	*P*	*Q*	*R*
—	$\frac{7}{32}$	0·418	0·415	0·234	0·239	0·178	0·104	0·313	0·501	0·295	0·021	0·167	0·312	3·25	0·275	0·112	0·099	0·261	0·748
—	$\frac{1}{4}$	0·450	0·447	0·273	0·263	0·200	0·112	0·355	0·565	0·336	0·022	0·180	0·336	3·50	0·296	0·121	0·107	0·281	0·806
$\frac{1}{4}$	*$\frac{9}{32}$ $\frac{5}{16}$	0·530	0·527	0·313	0·307	0·232	0·132	0·410	0·653	0·387	0·050	0·212	0·395	5	0·348	0·142	0·126	0·331	0·949
$\frac{5}{16}$	$\frac{3}{8}$	0·605	0·602	0·391	0·359	0·277	0·151	0·496	0·786	0·470	0·063	0·242	0·451	5	0·398	0·162	0·144	0·378	0·083
$\frac{3}{8}$	$\frac{7}{16}$	0·715	0·712	0·469	0·427	0·331	0·178	0·593	0·939	0·563	0·075	0·286	0·533	6	0·470	0·192	0·170	0·447	0·280
$\frac{7}{16}$	$\frac{1}{2}$	0·825	0·822	0·547	0·494	0·384	0·206	0·689	1·090	0·654	0·088	0·330	0·615	6	0·542	0·221	0·196	0·516	1·477
$\frac{1}{2}$	$\frac{9}{16}$	0·925	0·922	0·583	0·546	0·419	0·231	0·747	1·186	0·708	0·100	0·370	0·690	8	0·608	0·248	0·220	0·578	1·656
$\frac{9}{16}$	$\frac{5}{8}$	1·015	1·012	0·656	0·604	0·466	0·253	0·833	1·321	0·791	0·113	0·406	0·757	8	0·667	0·272	0·242	0·634	1·817
$\frac{5}{8}$	*$\frac{11}{16}$	1·105	1·102	0·729	0·661	0·513	0·276	0·920	1·455	0·873	0·125	0·442	0·824	9	0·726	0·296	0·263	0·691	1·978
*$\frac{11}{16}$	$\frac{3}{4}$ *$\frac{13}{16}$	1·205	1·202	0·802	0·723	0·562	0·301	1·009	1·596	0·958	0·138	0 482	0·899	9	0·792	0·323	0·287	0·753	2·157
$\frac{3}{4}$	$\frac{7}{8}$	1·305	1·302	0·875	0·785	0·611	0·326	1·098	1·736	1·043	0·150	0·522	0·974	10	0·857	0·350	0·311	0·816	2·336
*$\frac{13}{16}$	*$\frac{15}{16}$	1·395	1·392	0·880	0·824	0·632	0·348	1·127	1·790	1·068	0·163	0·558	1·041	10	0·917	0·374	0·332	0·872	2·497
$\frac{7}{8}$	1	1·485	1·482	0·948	0·880	0·677	0·371	1·209	1·918	1·146	0·175	0·594	1·108	12	0·976	0·398	0·353	0·928	2·658
*$\frac{15}{16}$	—	1·585	1·582	1·016	0·941	0·724	0·396	1·294	2·052	1·227	0·188	0·634	1·182	12	1·041	0·425	0·377	0·991	2·837
1	1$\frac{1}{8}$	1·675	1·672	1·083	0·997	0·769	0·418	1·376	2·181	1·305	0·200	0·670	1·250	15	1·100	0·449	0·399	1·047	2·998
1$\frac{1}{8}$	1$\frac{1}{4}$	1·870	1·864	1·125	1·090	0·826	0·467	1·465	2·335	1·386	0·225	0·748	1·395	15	1·229	0·501	0·445	1·169	3·348
1$\frac{1}{4}$	*1$\frac{3}{8}$	2·060	2·054	1·250	1·203	0·998	0·514	1·622	2·583	1·534	0·250	0·824	1·537	18	1·353	0·552	0·490	1·288	3·688
*1$\frac{3}{8}$	1$\frac{1}{2}$	2·230	2·224	1·375	1·309	1·044	0·557	1·775	2·823	1·680	0·275	0·892	1·664	18	1·465	0·598	0·531	1·394	3·992
1$\frac{1}{2}$	*1$\frac{5}{8}$	2·420	2·414	1·500	1·422	1·086	0·604	1·933	3·073	1·830	0·300	0·968	1·805	21	1·590	0·649	0·576	1·313	4·332
*1$\frac{5}{8}$	1$\frac{3}{4}$	2·590	2·584	1·625	1·528	1·170	0·647	2·086	3·313	1·976	0·325	1·036	1·932	21	1·702	0·694	0·616	1·619	4·637
1$\frac{3}{4}$	2	2·770	2·764	1·750	1·637	1·256	0·692	2·240	3·556	2·122	0·350	1·108	2·066	23	1·820	0·742	0·659	1·731	4·958
*1$\frac{7}{8}$	—	3·030	3·024	1·875	1·780	1·359	0·757	2·418	3·844	2·289	0·375	1·212	2·260	23	1·991	0·812	0·721	1·894	5·424
2	2$\frac{1}{4}$	3·160	3·154	2·000	1·869	1·435	0·789	2·559	4·062	2·425	0·400	1·264	2·357	26	2·076	0·847	0·752	1·975	5·657

* The B.S.I. recommends that for general use the nuts and bolts corresponding with these spanner sizes be dispensed with.

GRAPH OF POWER REQUIRED TO BLANK PRESSINGS FROM MILD-STEEL SHEET



GRAPH SHOWING RELATION OF LOAD TO STRESS ON RIVETS



PRODUCTION CONTROL

Production control is the planned co-ordination of all the movements of the elements of a production programme.

Planning consists of anticipating all the aspects of these movements and designing a system which will ensure the proper co-ordination. Successful planning depends upon covering as wide a field as possible in the collation of information and its application in this system. The main aspects to be covered are:

Material.

Machines, tools, and equipment.

Methods and operations.

The information which is to be collated consists of:

Material.—Specification, quantity, source, and delivery date.

Machines, Tools, and Equipment.—Capacities, availability, and requirements.

Methods and Operations.—Determination of best methods and resulting operations required. Time allowances for each operation. Sequence of operations.

Mechanism of production control uses above information to initiate, produce, and keep in movement the goods required, so that they shall be available

MANUFACTURING SCHEDULE

Customer	Order No	Qty	Description	Date of receipt	Dly promised	Works Order No.	Issued	Work commenced	Additional load on shops					Total existing load					Deliveries
									A	F	G	T	M	A	F	G	T	M	

Fig. 1.—Schedule of manufacturing programme.

at the time assigned for their delivery. Co-ordination of the activities of each department concerned in the manufacture of the parts is the control function undertaken, and to this end the whole system is designed.

Forms of Manufacture.—Manufacture against specific orders. Mostly non-repetitive. Jobbing organisations.

Manufacture for stock (*a*) for mass-produced repetitive parts for internal use; (*b*) for mass-produced non-repetitive customer's order; (*c*) continuous process, such as manufactured metals.

Sub-divisions of planning functions are as follow:

(1) Connect design with manufacture to effect most economical product.
(2) Consider materials most suitable from manufacturing view-point.
(3) Plan method.
(4) Design and order tools, machines, and equipment.
(5) Determine time allowances.
(6) Determine grades of labour required.
(7) Determine wage rates applicable.

Production Department Functions.—(1) Analyse order to determine number required of each detail.

(2) Determine material required as to (*a*) quantity; (*b*) specification; (*c*) source; (*d*) purchase instructions; (*e*) delivery dates.

(3) Scheduling and routing of parts in process.

(4) Determination and charting of machine load.

(5) Progress chasing of parts from point to point of manufacture.

Analysis of order should be undertaken to determine:

(*a*) Load added to existing manufacturing programme.

(*b*) Whether parts shall be made in factory or bought out.

Schedule of manufacturing programme (Fig. 1) should exist and show :

(*a*) Customer and customer's order number.
(*b*) Quantity and description of parts on order.
(*c*) Date of receipt of order.
(*d*) Date of delivery promise.
(*e*) Internal order number and date of issue.
(*f*) Date manufacture commenced.
(*g*) Additional load on plant (detailed, if necessary, into load on various units).
(*h*) Current total load on plant (detailed, if necessary, into load on various units).
(*j*) Dates and quantities of deliveries made.

DESCRIPTION OF PART............ PART No. ....

Order No	Quantity	Current total	Deliveries											

Fig. 2.—Parts record card.

Analysis of parts required is made from parts list or schedule issued with necessary drawings from the Drawing Office. Each part should have own record card (Fig. 2), listing number to be made on each order and current total in hand, number delivered, etc.

Determining whether parts shall be made or bought out should be considered from following angles :

(*a*) *Cost :* Standardised parts—nuts, bolts, washers, etc.—may usually be purchased cheaper than can be undertaken by plant. Same applies to specialised manufacture.

MATERIAL LIST. TYPE........................ JOB No. ....

Item No	No. off	Part No	Description of part	Material required	Q'ty Reqd.

Fig. 3.—Material list.

(*b*) *Load :* Existing load may necessitate passing some work on to sub-contractors with necessary facilities.

(*c*) *Inspection :* Difficulties may accrue with parts made out if accuracy is close or specialised knowledge of parts not available outside.

(*d*) *Contact :* Closer contact with whole process available with internal manufacture, resulting in certain knowledge of quality.

Material required is determined by reference to part drawings and may be summarised by the following methods :

(*a*) Material list for each specific job (Fig. 3).

PART OR MATERIAL										SOURCE									
Date	Order No	Amt allocated	Total reqd	On order PA	Order No	D/d	% Stdg	Issued	Stock	Date	Order No	Amt allocated	Total reqd	On order PA	Order No	D/d	% Stdg	Issued	Stock

Fig. 4.—Material summary (gives particulars of material for each job).

(*b*) Material summary for each kind, size, and specification required, listing material particulars for each job undertaken (Fig. 4).

(*c*) Stores ledger card (Fig. 5) (described later under Material Control).

Action necessary when material required is determined will consist of :

(*a*) Ascertainment of availability from stock.

(*b*) Purchase requisition on Buying Department (Fig. 6).

(*c*) Entry on records of delivery promise.

(*d*) Follow up by, or on, Buying Department for fulfilment of promise (Fig. 7).

(*e*) Posting of delivery dates (Figs. 4 and 5).

(*f*) Posting of dates of material issue (Figs. 4 and 5).

Manufacturing Order may take various forms :

(*a*) Order from Sales Department to Production Department for specific customer's order (Fig. 8).

(*b*) Production Department order on manufacturing departments for supply of parts and assemblies to fulfil (*a*) (Fig. 9).

(*c*) Production Department order on manufacturing departments for replenishment of stock for repetitive production (Fig. 9).

(*d*) Stores order on Production Department for supply of parts for replenishment of stock as in (*c*) (Fig. 10).

Kind of order used will depend on form of manufacture undertaken by organisation, for instance :

(*a*) Is most used in jobbing work.

(*b*) Is likely in both jobbing work and repetitive work.

(*c*) Is used for mass-produced goods, either for supply to customers' order or

Part No.			Description							
Used on				Source			Min. stock			
ON ORDER			D/d to STORES			ISSUED			BALANCE	
Order No.	Date	Q'ty	Order No	Date	Q'ty	Order No.	Date	Q'ty	Date	Q'ty

Fig. 5.—Stores ledger card.

for internal use on mass-assembled goods.

(*d*) Is similar to (*c*), but the internal organisation used is on a different basis.

The **Manufacturing Order** should give following information (Fig. 9) :

(1) Part number and description of part.
(2) Quantity on order.
(3) Date of issue of order.
(4) Date delivery is required.
(5) Material required.
(6) Route work is to follow.
(7) Provision for following entries when work is in progress :

Reqisition for productive material.
From production dept. to buyer.
Please supply:–

Q'ty.	*Description*	*Prodn. order No.*	*Deliver to*	*Date reqd*

Date......................... *Signed.........................*

Fig. 6.—Requisition on buyer for productive material.

(*a*) Batch number (if order is divided up).
(*b*) Quantity in batch.
(*c*) Operation reached.
(*d*) Quantities finished at operation as above.
(*e*) Date each quantity is finished.
(*f*) Good parts passed to next operation or stores.

Stores Requisition for Manufacturing Order is made out either by Production Department for issue with order or by shop when job is about to be put in hand (Fig. 11). Information required as follows :

(1) Manufacturing Order number.
(2) Date of issue of requisition.
(3) Departmental symbol of department requiring or ordering material.
(4) Symbol of Stores Department from which ordered.
(5) Quantity and specification of material.
(6) Date material required.
(7) Signature of person authorised to make out requisition.
(8) Signature of person issuing.
(9) Signature of person entering issue on Stores Records.

Job Card is issued to operator working on parts to cover time aspects of job (Fig. 12). It shows :

(*a*) Manufacturing Order number.
(*b*) Part number.
(*c*) Operation number.
(*d*) Machine number on which work is done.
(*e*) Time allowed and price to be paid.
(*f*) Date of issue.
(*g*) Quantity in batch.
(*h*) Quantity finished.
(*j*) Quantity passed.
(*k*) Quantity scrapped, chargeable to company, or through fault of operator.
(*l*) Quantity for which operator is to be paid.

Job card serves the following purposes :

(*a*) Informs operator of particulars of operation, time allowed, and price paid.

SMITH ENGINEERING Co. Ltd.
Smith st.
London W. 1. *Date as postmark*

Your attention is drawn to the following goods on our order No. which are now over due.

Early fulfilment of our order is now urgently required

Yours faithfully.
Buyer

Fig. 7.—Follow-up card on supplier for goods due or overdue.

(*b*) Serves as progress card for entries on manufacturing order and/or control board.

(*c*) Used by Wages Department to compile operators' earnings.

(*d*) Used by Cost Department to compile job cost.

Move Card can be attached to job card by perforation and shows the following information (Fig. 12):

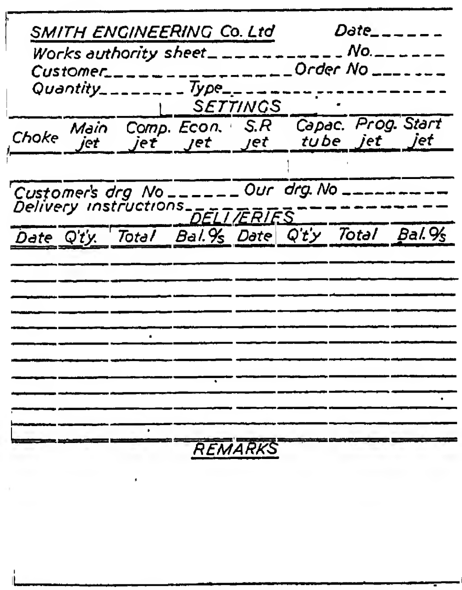
(*a*) Manufacturing Order number.

(*b*) Part number.

(*c*) Operation number covered.

(*d*) Quantity good.

Move card is filled at (*a*) (*b*) (*c*), and (*e*) by Production Department when issuing job card and at (*d*) by Inspection Department when checking goods. This card stays with the parts (a bracket being provided on the container if possible) and informs the shop office which is the next operation.



SMITH ENGINEERING Co. Ltd Date______

Works authority sheet___________ No.______

Customer________________Order No _______

Quantity_______ Type_____________________

SETTINGS

Choke	Main jet	Comp. jet	Econ. jet	S.R jet	Capac. tube	Prog. jet	Start jet

Customer's drg No ______ Our drg. No _________

Delivery instructions_____________________

DELIVERIES

Date	Q'ty.	Total	Bal.%	Date	Q'ty	Total	Bal.%

REMARKS

Fig. 8.—Sales Department order for customer's goods.

View Ticket is also attached to the job card by perforation and gives the following information (Fig. 12).

(*a*) Manufacturing Order number.

(*b*) Part number.

(*c*) Operation number covered.

(*d*) Quantity viewed.

(*e*) Quantity good.

(*f*) Quantity rejected.

(*g*) Quantity scrap.

The card is filled in at (*a*) (*b*), and (*c*) by the Production Department when issuing the job card, and at (*d*) (*e*), and (*f*) by the Inspection Department. When the latter have made necessary use of the card, it is passed to Production Department for posting on to Manufacturing Order as confirmation of entries on job card.

Scheduling consists in entering on some form of schedule the periodic progress of work of all kinds. The schedule may take a variety of forms:

(*a*) Marking against Manufacturing Order the movement of the job from issue of order to dispatch (Fig. 13). Applicable only on small orders, repair jobs, and general jobbing work not involving a multiplicity of parts or large number of operations.

(*b*) Ledger form with quick reference for entries or review (Fig. 14). Not very efficient or applicable to work of wide range. Various forms of coding provide quicker aid.

(*c*) Gantt Charts covering specific orders or standard parts (Figs. 15–17).

(*d*) Control Board with suitably devised system of showing progress (Figs. 18–20).

Gantt Charts (Figs. 15–17) provide ready means of signalling variety of information required about job in progress. By suitable code of lines specific

Originating order________________ WORKS ORDER No ______________
Quantity__________________ Required by__________ No ________
Excess %________ Date issued_____ No finished________
Part No.________ Deficit %__________ Date completed__________________
Description______________________________
Components______________________________
____

Job No.	1	2	3	4	5	6	7	8	9	0
Opn. No										
Date										
Issued										
Total										
Transferred										
Total										
Complete										
Total										

Fig. 9.—Works order.

types of movements, dates, periods overdue, and quantities delivered can be indicated. Fig. 15 shows form of chart in which date of commencement and desired date of delivery are indicated against specific items. A black line covers this period, and other lines indicate desired dates for commencement and completion of various operations. Fig. 16 shows the quantities made in a given period against the quantity desired in that period. The full line shows the desired monthly output, plotting against the month horizontally and the quantity vertically. The dotted line shows the actual output per month. Fig. 17 shows chart giving date on which it is desired work shall be handled by certain machines, together with the date work is actually put in hand and completed.

Control Boards cover a great variety of designs, of which Figs. 18–20 show a few examples. Fig. 18 shows a simple design in which the main parts of an assembly are entered as they pass from shop to shop. This form would be used when the bulk of the plant's production was of standard type and it was only necessary to signal the movement of certain items. Fig. 19 also shows a simple method of signalling the stage which the product (in this case carburettors undergoing overhaul) has reached.

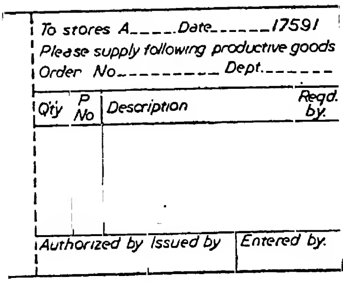
The board shows the following functions:

To production dept. Date______
Please note stock position:—

P No.	Description	O/S orders	Stock	Min. stock	Q'ty. orderd	Order No.

Storekeeper__________

Fig. 10.—Stores order on Production Department (chiefly used for mass-produced repetitive parts).


To stores A____ Date______ 17591
Please supply following productive goods
Order No.________ Dept.______

Q'ty	P No	Description	Reqd. by

Authorized by | Issued by | Entered by

Fig. 11.—Stores requisition.

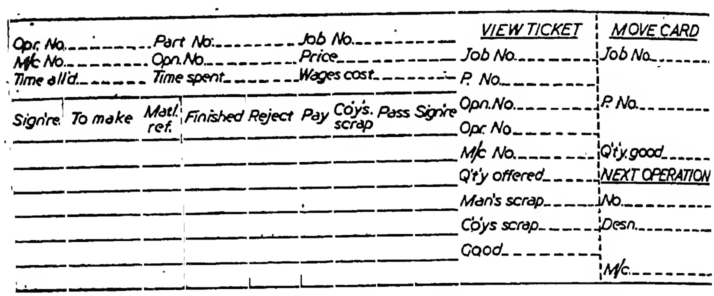
(*a*) Type of carburettor.
(*b*) Stage which carburettor has reached.

A small tab is made out on which the particulars of each such carburettor is entered, such as:

(*a*) Type of carburettor.
(*b*) Serial number of carburettor.
(*c*) Order number.
(*d*) Customer.
(*e*) Date required.

Opposite each type of carburettor given is a horizontal line of light springs which are used to clamp the tab in the particular column referring to the stage at which the carburettor has arrived. It is the duty of the progress clerk to move the tab as its movement is reported.

Fig. 20 shows a more elaborate type of control board, which gives any full particulars of the movement of parts. Many well-known firms to-day specialise in supplying various forms of production-control systems, either the types illustrated (Figs. 18–20) or by card-index systems, and consultation of these will be adequately repaid.


Opr. No.________ Part No.________ Job No.________
M/c No.________ Opn. No.________ Price________
Time all'd.______ Time spent______ Wages cost______

Sign're	To make	Mat'l ref.	Finished	Reject	Pay	Co'ys. scrap	Pass	Sign're

VIEW TICKET
Job No.________
P. No.________
Opn. No.________
Opr. No.________
M/c No.________
Q'ty offered______
Man's scrap______
Co'ys scrap______
Good________

MOVE CARD
Job No.______
P. No.________
Q'ty good______
NEXT OPERATION
No.________
Desn.________
M/c.________

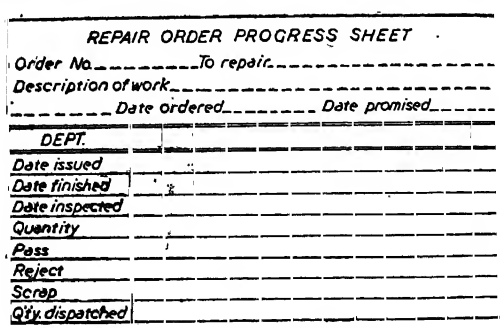
Fig. 12.—Job card (also view ticket and move card).

Objects of Production Control Boards.—(*a*) To signal by some adequate means that certain actions have to be taken.

(*b*) To signal the stage to which a given part has arrived.

(*c*) To signal when parts have not arrived at the stage which was planned.

The design of the control board should always aim at giving these three signals, and any system used which adequately does so to the extent necessary can be considered successful.


REPAIR ORDER PROGRESS SHEET
Order No.________ To repair________________
Description of work________________________
________ Date ordered________ Date promised______

DEPT.		
Date issued		
Date finished		
Date inspected		
Quantity		
Pass		
Reject		
Scrap		
Q'ty dispatched		

Fig. 13.—Simple progress sheet.

Routing is the means by which work is followed from point to point in the productive chain. Its original aspect in the manufacturing programme is that of determining the route which the work is to follow in its progress. This includes determining the operations, machines and departments which will be used in making the parts. After deciding these, the information is entered in some appropriate form for issue. However, the first step in arriving at the route is made by the Planning Department in determining the best method to be used. This is based on :

(*a*) Past experience in the manufacture of the same or similar parts.
(*b*) Best use of available plant for parts of new design.
(*c*) In process work, route is obvious from the nature of the process.
(*d*) In some non-engineering production, route is readily determined by the nature of the article.

PROGRESS SHEET Date_______
Order No._____Customer____________________
To make_____Description____________________
Route__________Date ordered______Reqd______

	Material										
Date issued											
Date finished											
Date inspected											
Quantity											
Pass											
Reject											
Scrap											
Qty dispatched											
Signatures											

Fig. 14.—Ledger-form progress sheet.

Production Planning, therefore, commences with an analysis of each part and the best method of manufacture. In the light of the above four bases, the Planning Department determines this method and makes necessary records on a process sheet, operation layout, operation sequence record, or route card.

The Methods to be employed are necessarily determined as the result of the experience of the Planning Department personnel, who should therefore be very familiar with the problems of the class of work in hand. The experience available for making these decisions has to extend to the following aspects of production :

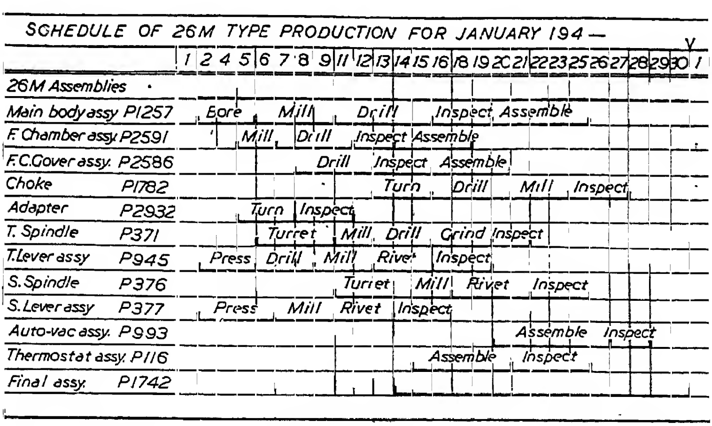


Fig. 15.—Gantt chart : Type showing date of commencement and desired date of delivery.

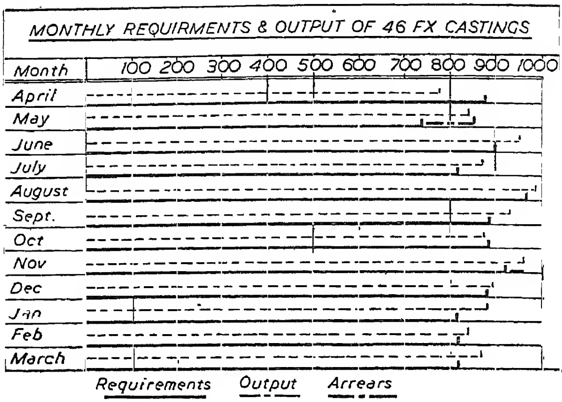


Fig. 16.—Gantt chart: Type showing quantities required in various months, with actual outputs and arrears.

(1) Best use of plant available.

(2) Ability to determine which method is the more economical.

(3) Reliable estimates of the times for production, allowances necessary and suitable incentives to ensure maximum production.

(4) Class of labour most suitable for the job.

Operation planning is the function of determining those operations which will be necessary on the given plant with suitable labour to make the part.

Process Sheet.—These are more frequently used where the production is some form of processing, e.g. plating, heat treatment, chemical extraction, etc. Fig. 21 shows two such sheets issued respectively for the electrolytic production of white lead and the electro-zinc plating of steel screws.

Operation Layout.—This is issued to give fullest information possible about the manufacture of a given part or assembly. The information so given is as follows (Fig. 22):

(1) Name and number of part or assembly.
(2) Material, or parts, from which made.
(3) Summary of route through which part, or parts, travel, i.e. departments from which material or part originate, departments which work upon, treat or inspect parts or assembly, place to which parts are sent after work is complete.
(4) Number and description of operation, department which performs it, machines, tools, gauges, etc., used.
(5) Time aspects of the job.
(6) Signatures of responsible officials.

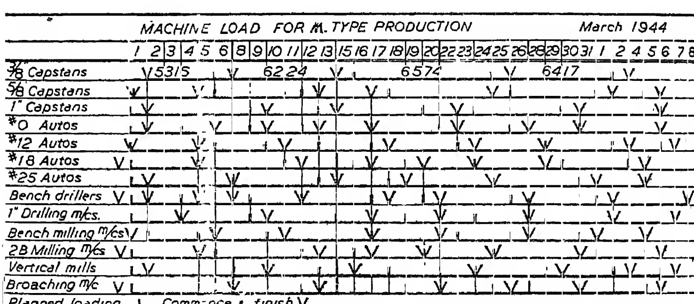


Fig. 17.—Gantt Chart: Type showing dates on which machines must handle certain orders

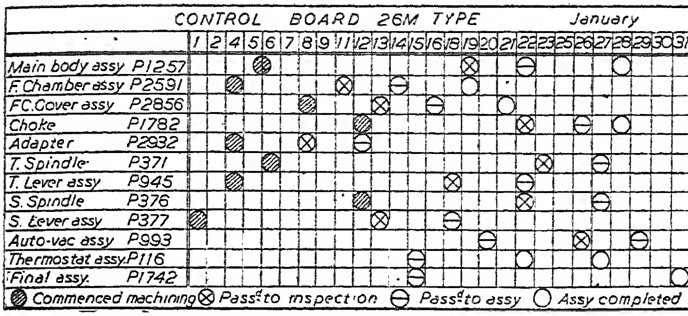


Fig. 18.—Control board: Design of board on which dates work is passed to certain departments are signalled.

Operation Sequence Record will mostly be issued where it is not thought necessary for the operation layout to be in the possession of the routing clerk. It forms a ready means of indicating the route which the work has to follow (Fig. 23).

Route Cards form a simple means of indicating to the Production Department the route the work is to take. The one shown (Fig. 24) gives the following information:

(*a*) Route.
(*b*) Material required.
(*c*) Tool position.

Machines, tools, and methods to be used require that the Planning Department has available a wide range of data (see p. 960). This should be tabulated in most convenient forms, according to the function.

Machines and Equipment.—The information regarding these will consist of the following:

(1) *Capacity Charts* (Figs. 25 and 25*a*) giving dimensional, functional, time, and performance details of each part of the plant. Very useful data can be entered thereon, which will aid the Planning Department in arriving at accurate forecasts regarding the best machines to use and the time jobs will take.

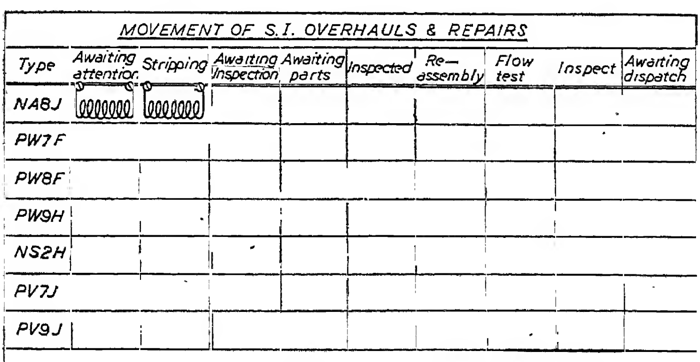


Fig. 19.—Control board: Design of board signalling stage at which repair or overhaul has arrived.

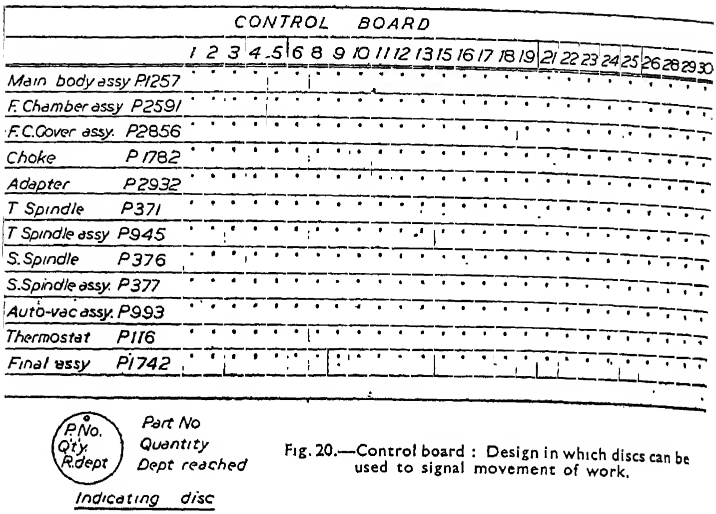


Fig. 20.—Control board: Design in which discs can be used to signal movement of work.

(2) *Loading Charts* (Fig. 26) are filled in with the information provided by the Planning Department according to its estimate of the best machine and the time jobs will take. The chart illustrated here is in the form of a Gantt Chart, and the information is made available by means of the Operation Layout. The Production Department clerk responsible for the recording on the Loading **Chart** enters the time each batch will occupy the given machine, according to the manufacturing programme.

(3) *Time or number of machines required* will be shown clearly by the Loading Chart, and it will be necessary to adjust either the size of the batches, lengthen the delivery date, or acquire further machines according as the Loading Chart signals.

Tools are ordered by the Planning Department after the method has been decided. These will be either made in the plant, or bought out. The decision as to the type of jig, tool, or fixture to use will depend upon a number of factors—

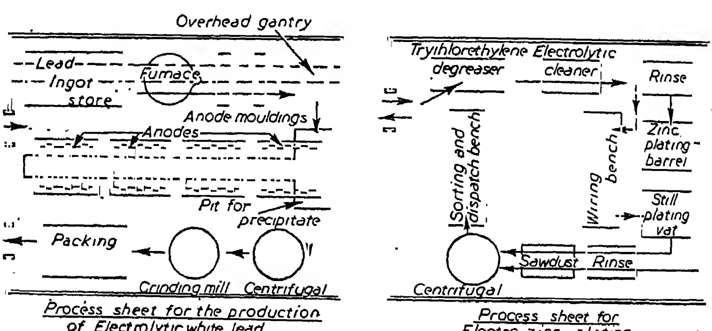


Fig. 21.—Typical process sheets.

(a) Number of parts required.
(b) Possibility of repeat orders.
(c) Type of labour available.
(d) Plant available.
(e) Urgency with which parts are required.

Regarding (a) and (b), the question of costs arises and an estimate has to be made to settle this point.

Determining the Economic Form of Tool.—To determine how much more

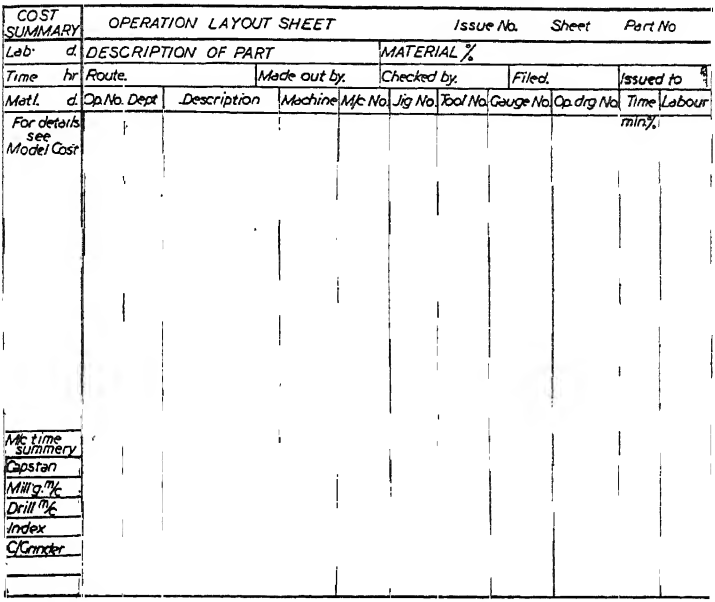


Fig. 22.—Operation layout sheet.

shall be spent on making one type of jig as against another, it is necessary to know the following factors :

(a) Increased cost of the jig, tool, or fixture.
(b) Saving in direct labour cost.
(c) Saving in indirect labour cost.
(d) Saving in value of machine time.
(e) Increase or decrease of setting time.

Let I = Increased cost of the jig, tool, or fixture.
D = Saving in direct labour cost per piece.
L = Saving in indirect labour cost per piece.
M = Saving in cost of machine time.
S = Increase or decrease in value of setting time.
(M and S are expressed in a given rate per hour which it is expected the machine should earn.)
R = Capital value of extra cost of the jig, tool, or fixture expressed as a percentage of the increased cost at expected return on capital.
G = Number of pieces in the batch.

Then

$$G(D + L + M) > I + (I \times R) + S.$$

Jig and tool design must take full account of the type of labour which will be used for the work. This involves considering suitable means of fool-proofing, avoiding unwieldiness, and ease of use with least amount of training. The jigs and tools must necessarily be those best suited to the plant available as regards size and ability to make best use of capacity in speeds and feeds. Knowledge of up-to-date tool designs and use of latest cutting materials should exist and of the possibility of making best use of these on the existing plant. Ability to determine to what tolerances the existing plant will work is of prime importance, and this should be used both in planning methods and guiding the Designs Department. A knowledge of the steps to be used in getting the best results from the inspection methods is necessary so that the three aspects of economical production, ease of flow, and desired functional operation shall be obtained.

Tools urgently required will often necessitate making tools of simpler design, which, however, will not give best results from an economy point of view. This should always be made clear to Higher Control, who endeavour to push delivery against the advice of those desiring economic manufacture.

Time Study.—After the operations decided upon are in hand, this is the only truly permanent way of checking the time required for each operation. However, in planning the method estimates will necessarily have to be made both for the operating times and the setting times. Carefully checked and authenticated times for the machine, which should be given on the Capacity Chart (Fig. 25), will enable reasonably true estimates to be made. An analysis of each machine to determine accurately the time for various manipulative functions will amply reward in this matter.

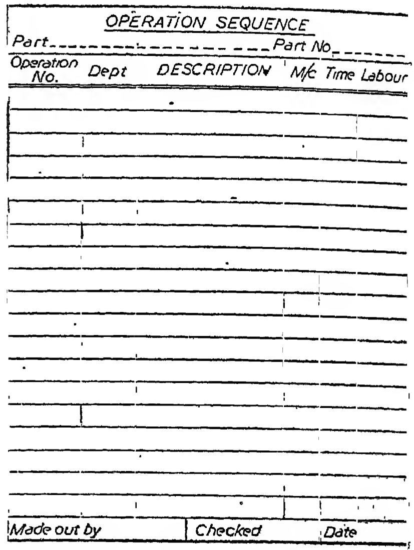


Fig. 23.—Operation sequence sheet.

Methods of Determining Operation Sequence. — The determination of the best operations sequence is fixed in a number of ways, which make themselves fairly obvious according to the job in hand. Factors affecting the sequence are :

(1) Material or process to be worked on—obviously moulding must occur before casting and, as in Fig. 21, the sequence is determined by the process itself.

(2) Small-quantity production necessitates the utmost use of the available plant, and the sequence should be as fluid as possible.

(3) The normal layout of the plant so that the route followed shall be as short as possible.

(4) By adjustment after original sequence has been tried out.

Economy of movement must be the chief aim in planning the sequence, and this should be followed as much as the operations will allow. To this end the plant, gangways, stores, and services should be laid out. However, where the production is diverse it may not be possible to do this 100 per cent., but consideration should be given to the possibility of planning as much of the production as will allow the product to follow the shortest route.

Plant Layout.—Production may follow three main types :

(1) Continuous process, such as metallurgical, chemical, and food.

(2) Repetitive, such as car, clothing, footwear, and electrical appliance production.
(3) Intermittent, such as structural steel, locomotives, industrial engines, and generating-plant production.

In each case the guide to the layout is the process sheet or operation layout, and a study of these will pretty directly indicate the type under which production falls. Inevitably the best form of layout is that which could afford each part a straight-line route from operation to operation, but where the number of types of parts to be made is large and diverse, such a condition is not possible of application to each part. The layout, therefore, will be of four main kinds :

(1) Straight-line.
(2) Functional or group.
(3) Product or departmental.
(4) A combination of any or all of the above.

Straight-line production will be that in which the work moves always in one direction, without deviation, continuously from point to point until completion.

This type has obvious advantages, the chief of which are :

(*a*) Ease of supervision.
(*b*) Reduction of handling.
(*c*) Low cost of production.
(*d*) Greater possibilities of using mechanised means of handling.

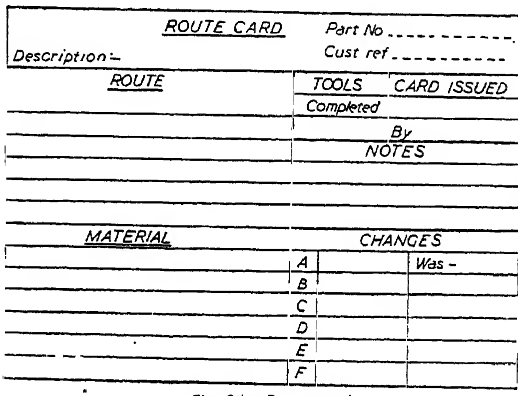


Fig. 24.—Route card.

Many plants use this method, particularly for mass-produced goods, and it is of general application in the motor-car industry. Great ingenuity can be used in planning the layout under these conditions, and it should not be feared to depart from the conventional in the planning. For instance, the imposition of a machine in an assembly line or of a partial or full assembly between machining operations may often be resorted to with success. Often it will be found possible to equip whole departments on a line basis, the department being located at a point which will bring the department into the line of the main product. This also applies to stores. Storage of raw material or unmachined parts should be made at the point where they are machined, and the machined parts passed to the stores most conveniently situated at the point of further use, say assembly. The conditions for successful operation of the straight-line flow are :

(1) Assured market for product.
(2) Ready supply of labour.
(3) Adequate supply of raw material and finished parts delivered at the point in line at which they are required.

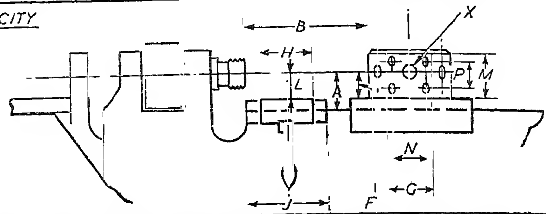
The planning of a straight-line production layout also calls for a suitable kind of production control so far as the clerical work is concerned. This should aim at :

(*a*) Providing material on time at the production point.
(*b*) Timely signalling of production defects—shortage of material, machine breakdown, labour shortage, etc.
(*c*) Co-ordination between buying and progressing.

Functional or group layout is that in which the machines of a given type are

TYPE & MAKE	No 2a WARD Capstan Lathe		M/c. No.	254 M	SHOP	
SIMILAR M/cs	256	LOCATION.		M/c SERIAL No.	WT/A 138/1	

CAPACITY



HEADSTOCK-Swing over Bed A.	11 ¼"	Swing over Slide L.	2 5/8"	Barfeed by	Hand	Auto Chuck	
HOLE thro' feed finger	X	feed tube	X	Spindle	1 3/8	Max. feed thro' headstk	
SPINDLE SPEEDS-& reverse FORWARD	95, 175, 321, 605, 1112, 2041.						
TURRET 6 holes x 1 dia	Size flats GxM	3 ¾" x 3 1/8"	Fixing holes NxP	2 5/8" x 2 ¼".			
Max. distance Turret to Spindle Nose	19 ¾"	Ht. of hole Centres over Cross Slide F	2 5/8				
Power Feed to Turret.	80, 165, 120, 240,	revs. per in. of travel.					
CROSS SLIDE-feed	S	Width H	4 5/8"	Moves along Bed J	11 ¾"	Max. between Posts	8 ¾"
Takes Tools	½" sq.	Circular Form Tools	x	dia.			
Power feed to Cross Slide	None	revs. per in. of travel.					
EQUIPPED WITH PUMP.	Yes	EQUIPPED WITH STOCKTUBE.	Yes	Outside dia.			
DRIVE-R.P.M. pulley	900	Dia.	8"	Width	2½"		

FLOOR PLAN

EQUIPMENT AVAILABLE Set round collets 3/8", 7/16", ½", 5/8", ¾", 7/8", 1", 1¼", ½" A/F. sq. Drill chuck; ½ Coventry diehead; 0468 Bar stop; 14084 Roller Ending Tool Holder; 13545 Roller Steady Box Holder; 0527 Tap Holder.

REMARKS

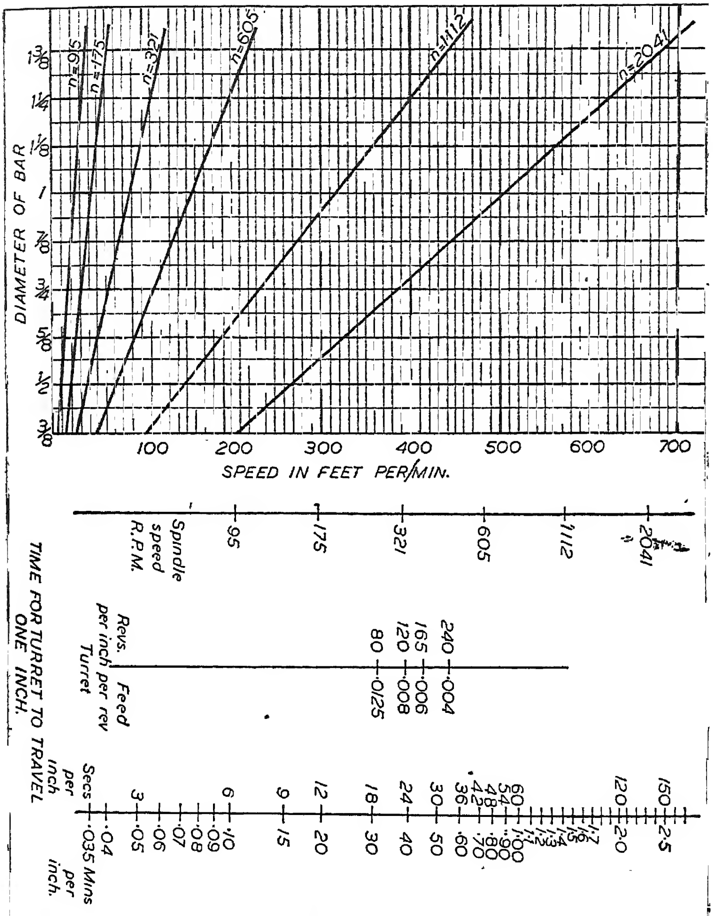
REPAIRS

Date	NATURE of FAULT	WORK DONE	LABOUR HRS.	MAT'L

DATE of PURCHASE	29-3-44	COND'N	New	SUPPLIER	Ward	COST	

Machine Data Chart—BAR FEED CAPSTAN M. 1052

Fig. 25.—Machine capacity chart: Obverse side, giving ull particulars of machine dimensional capacity.



TIMES FOR ELEMENTARY OPERATIONS IN SECONDS	
Open Collet, remove end of bar, wind back push rod, remove stock	38, 42, 35,
Tube to load position, pick up bar, wipe, insert, wind bar to stop, lock Collet	40, 41, 39.
Feed bar to stop (Includes opening Collet): 3, 3·2, 3, 2·6, 2·8, Av. 2·9 Min 2·6	
Elapsed time between above (a) & next movement, say form or run up Turret	1, 1·2
Run up Turret to commence cut: 1, 1·2, 0·9, 1, 1·3, Av 1·1 Min 0·9.	
Take Cross-slide tool to work: 2·4, 2·2, 3, 3, 2·6, Av 2·7 Min. 2·2	
Rotate Turret: One place 2 two places 4 three places 6	
Four places 7 five places 8 six places 9	
Pick off piece & place down after parting out: 0·6, 0·8, 0·6, 0·7, Av 0·7 Min 0·6.	

Fig. 25a.—Machine capacity chart: Reverse side, giving machining capacity and times of elementary operations.

grouped together irrespective of their relation to the flow of the work; thus, drilling machines in the drilling department, capstan lathes in the machining department, etc. The advantages of this type of layout are:

(1) Grouping together of skilled supervision with resultant increased efficiency.
(2) Maximum use of machines.
(3) Maximum efficiency of operator's skill.
(4) Greater flexibility of type of output.
(5) Lower capital cost of plant.

In this type of layout the work is placed at the machine, as required, and moved from machine to machine via necessary inspection operations according as the machine becomes vacant. The disadvantages of this layout are:

(*a*) Increase of handling.
(*b*) Greater difficulty in progress work.
(*c*) Increase in production-control clerical labour.
(*d*) Greater cost.
(*e*) Increase of inspection.

Product or departmental layout consists in grouping together all the processes and machines used in making one particular product. Thus, one department is devoted to the entire production of one of the organisation's products, in

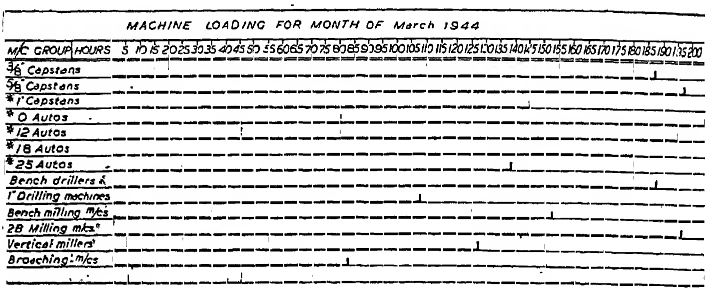


Fig. 26.—Gantt chart for machine loading.

full, from raw material to dispatch, or a common dispatch department is used for all products. The advantages of this layout are:

(1) Easier production control.
(2) Less floor space per product.
(3) Easier inspection.
(4) Less production-control clerical labour.
(5) Smaller volume of work in hand.
(6) Easier progress work.
(7) Work passes through process in quicker time.

The disadvantages are:

(*a*) Slightly greater cost.
(*b*) Skill of labour not so readily obtained.
(*c*) Capital cost of plant greater.

Combinations of the various production layouts are most likely to be met with in practice. Thus we find one part of a works engaged on line production whilst other departments will be on either functional or product production. A good example is usually found where the machining of castings is undertaken on a line basis, as also is assembly, whilst the production of parts from the bar is on either of the other systems. Assembly work lends itself most readily to line production, and this portion of the plant is usually so planned. The compromise thus effected serves to make the best layout, in which the advantages of each system result.

Progress work consists of setting production in motion at the planned time

and seeing that the motion continues as each planned stage is reached. There are two main forms of progressing :

(1) Physical—sometimes known as "chasing."

(2) Clerical.

In (1) the personal efforts of the clerk responsible, sometimes known as a "chaser," are used to see that the progress desired is attained. While admirable efforts are often made by this individual to ensure that the work flows as required, there is much to be deprecated in this system. Very often it involves personal influence to attain the end, is very largely dependent upon the goodwill and efforts of the individual, and generally suffers greatly by his absence.

The institution of (2), in which the movements are attained by a closely knit system of clerical checks and follow-up, provides the best means of attaining good progress work.

Organisation of progress work consists in applying the production-control system as laid down with adequate means of ensuring that each stage in the production is picked up when desired. The means already enumerated are those of issuing the necessary orders on the manufacturing departments, and making the entries on the schedule of movements in whichever form it consists—Gantt Chart, Control Board, or Card Index System. The use of some kind of form to show movement is necessary and, as previously indicated, exists in the Move Card and Inspection Card (Fig. 12).

Further functions of progress work consist of :

(1) Reporting idle-machine capacity.

(2) Reporting inadequacy of parts through rejection.

(3) Reporting delivery of wanted material.

Material Control

Material control consists in providing the necessary materials in the correct quantity and quality when required, without the disadvantage of holding unnecessarily large amounts. The chief aims, therefore, are :

(1) The ordering of the material at the proper time for delivery approximately at the time requred but not after.

(2) Ordering material to the correct specification.

(3) Ordering the quantities required for work in hand and to come in sufficient quantities, but not involving excessive investment.

(4) The physical and clerical checking of acceptance into and issue from the stores.

(5) Clerical functions connected with above.

Functions of material control will vary with the form of manufacture (see under "Forms of Manufacture," p. 960) but mainly consist of :

(1) Determining material required.

(2) Ordering material required from proper source.

(3) Acceptance into stores of material or parts and necessary clerical function in connection with this.

(4) Issuance of material or parts and necessary clerical function.

(5) Adequate checking of quantities as specified.

(6) Recording of inventories for purposes of cost determination or valuation of stock.

(1) *Determining material required* is sometimes Stores function and sometimes Production Department function. This is often dependable upon the form of manufacture, as under :

Manufacture against specific orders—mostly Stores function.

Mass-produced repetitive parts—mostly Stores function.

Mass-produced non-repetitive goods against customers' orders—mostly Stores function.

Continuous process or line production—mostly Production Department function.

(2) *Ordering material required* falls approximately into the same category of functions as (1), and will chiefly follow from these. (3) and (4) each fall into a physical and clerical function, and are mostly carried out by different operators for each function. However, the operator responsible for the physical functions is often required to perform some clerical work, such as that of compiling entries

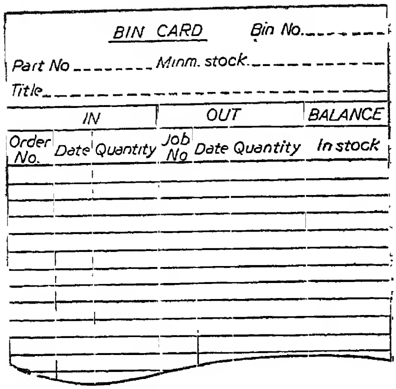


Fig. 27.—Bin card.

on the bin cards (Fig. 27) for the material or parts of which he is the custodian. The purely clerical function is chiefly carried out on a stores ledger system (Fig. 5), which forms an adequate means of recording all the aspects of Material Control.

(5) *Adequate checking of quantities* is a physical function used as a check against clerical records for the purposes of checking the correctness of these records and the honesty or efficiency of the physical function. Many organisations maintain a regular system of such checks, even daily, for these purposes. Apart from the aspect of financial loss which might be involved due to dishonesty or inefficiency is the equally important one of determining that stocks are as recorded, otherwise breakdown in production might result from such irregularities.

(6) *Recording of inventories for the purposes of cost determination or valuation of stock* is an important function when job costing and standards costs on balance-sheets are under consideration.

Stores procedure is generally as follows :

External Goods

(1) Receipt by Receiving Department.
(2) Acceptance into stores after necessary inspection.
(3) Retention against order for issue.
(4) Issue and necessary clerical work.
(5) Issue of stores debits and credits where necessary.
(6) Retention of finished goods against order for issue to dispatch.

Internal Goods

Follow the above procedure except that the acceptance of internal manufactured parts from the Inspection Department begins the procedure.

(1) **Receipt of Bought-out Goods.**—Procedure :
(*a*) Delivery to Receiving Department of copy of purchase order.
(*b*) Delivery of external goods.
(*c*) Checking of quantities.
(*d*) Receiving record passed to Buying Department.
(*e*) Dispatch of goods to Inspection Department with covering receiving record.

The issue of a copy of the purchase order (without price details) to the Receiving Department is an important point. Where this is not done, goods may be accepted by the department which were not intended for the organisation, and unnecessary work will be involved, including checking with the Buying Department as to whether they were rightly so delivered. A further aspect is that goods under or over delivered can be quickly notified to the Buying Department. The checking of the quantities will involve necessary counting or weighing appliances. These will consist, for counting, of suitable computing scales (Fig. 28) and for weighing of a suitable form of weighing machine. This latter may take a variety of forms from weigh-bridge to portable weighing platform. The choice of an adequate means will be a necessary consideration when designing the plant, as considerable loss of time and waste of labour may result if this point is not tackled at the outset.

Further, the provision of adequate means of transporting the goods must be undertaken. Labour capable of making reliable records for the goods received


POST-WAR PLANS
demand
STEEL EQUIPMENT
'ADJUSTEEL' SHELVING for ALL STORAGE PURPOSES — in ADJUSTABLE UNITS
The SOLUTION OF THE CYCLE STORAGE PROBLEM
Send for Catalogue RB/820
Send for Catalogue RB/201
Also Manufacturers of
STEEL OFFICE FURNITURE
CLOTHES LOCKERS
WORKS and STORAGE EQUIPMENT
'CONSOL' FLOOR PLATES
STILLAGES and
JACK TRUCK PLATFORMS
CONSTRUCTORS
TYBURN ROAD · ERDINGTON
BIRMINGHAM 24

is also a necessary prerequisite of the department. The goods when checked are passed to either the stores or more properly the Goods Inwards Inspection. A Receiving Record (Fig. 29) is made out in duplicate for issue to the Buying Department and the Stores or Inspection Department, as the case may be, giving the following particulars :

(*a*) Suppliers' name.
(*b*) Delivery-note number.
(*c*) Order number.
(*d*) Date of delivery.
(*e*) Quantity and description of goods.
(*f*) Signature of Receiving Department clerk.

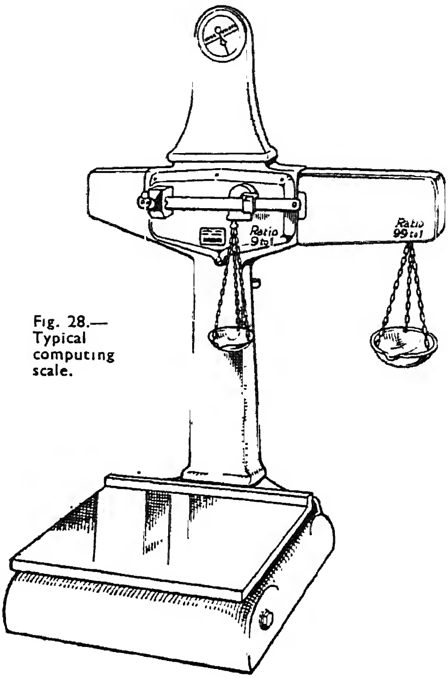


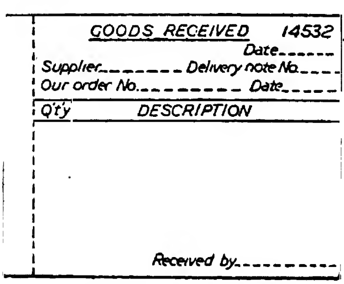
Fig. 28.—Typical computing scale.

Inspection of bought-out goods should be undertaken at the earliest possible time after their delivery. This, and other aspects of inspection, are dealt with under Control of Quality (see Index).

(2) **Acceptance into Stores from the Inspection Department.**—Procedure :

(*a*) Delivery to stores with necessary Move Card.
(*b*) Checking of quantities.
(*c*) Entry of quantity particulars on to Bin Card in the " In " column (Fig. 27).
(*d*) Storage into allocated bin.
(*e*) Passing of Move Card with quantity as checked to Stores Office.

The checking of the quantity delivered to the stores after it had already been counted by the Inspection Department may seem an unnecessary operation, but the amount of recrimination which follows through inefficient counting at one point makes this both necessary and profitable. The passing of Move Cards to either the Stores Office or Production Control Department should be done in an orderly manner, the best system being the introduction of an internal post by means of which the cards are collected from given points at certain specified times (say hourly). We deal more fully with the allocation of bins and storage space in a later section (p. 981).



GOODS RECEIVED 14532
Date......
Supplier....... Delivery note No....
Our order No......... Date.....
Q'ty DESCRIPTION
Received by..........

Fig. 29.—Goods received record.

(3) **Retention against Order for Issue.**—The retention of the parts stored is, of course, the prime function of the stores. The orderly storing to some prearranged plan is vital, both to ease passing into storage and issue. The manner of storing the parts, i.e. loosely

heaped into the bin or wrapped or boxed, is matter for consideration. The careful wrapping or boxing of the parts carried out after the parts have been checked at acceptance will help in issuing the correct quantities and avoid counting at that operation.

(4) **Issue of parts from stores** is made only against a requisition properly authorised (Fig. 11). An important point which should have consideration here is that of supplying the parts issued in the work-trays or bins from which they are to be used at the work-place. The design of suitable work-trays for placing in the correct position at the work-place is a function of the Planning Department in conjunction with the Motion Study Engineer. Not only is this necessary, but when the trays have been designed on a basis of the correct sequence for the search, find, and grasp therbligs, it is necessary for the parts to be put into the correct tray on this basis. For this purpose, a suitable chart should be issued to show the manner in which the trays should be filled for issue.

The clerical work connected with the issue of the parts consists in the countersigning of the requisition by the storekeeper making the issue and passing it to the Stores Office for entry on the stores ledger.

(5) **Stores Debits and Credits.**—Where through spoilage, wastage, loss, or bad allocation, the quantity of parts or material issued against a stores requisition is found to be either inadequate or over-abundant, the issue of a debit or credit respectively is necessary. These form a means of making a further issue of parts

STORES DEBIT 6379
Date------
Please supply following productive goods
Order No.---------- *Dept.*------

Q'ty	*P No.*	*DESCRIPTION*

Reason:—
Authorized by:- *Issed by:-* *Entered by:-*

Fig. 30.—Stores debit note.

STORES CREDIT 2584
Date------
Please accept into stock following prodve goods
From order No--------- *Dept.*------

Q'ty.	*P No*	*DESCRIPTION*

Reason:—
Authorised by:- *Accepted by:-* *Entered by:-*

Fig. 31.—Stores credit note.

or material or the acceptance back into stores of the quantity over-supplied (Figs. 30, 31). The issue of these forms calls for a proper check by a person authorised to do so, and will require further action to prevent its recurrence.

(6) **Finished Goods—Storage and Dispatch.**—Finished goods may be held in stock for two purposes:

(1) Against contracts or orders having specified delivery dates.
(2) For dispatch when called for on casual or contract orders.

The finished stores should be situated as near the point of dispatch as possible or may even include the Dispatch Department within its precincts. With the instructions to dispatch are passed the Delivery Notes, usually in triplicate, which give the following particulars (Fig. 32):

(1) Customer.
(2) Customer's order number.
(3) Quantity and description of goods.
(4) Dispatch instructions and particulars of transport.
(5) Signature of dispatch clerk.
(6) Space for signature of person receiving goods.

The triplicate notes are usually disposed of as follows:

(1) Customer.
(2) Consigner.
(3) Carrier.

Stores Records.—One of the most important functions of successful store-

keeping is that of ensuring accurate records. The chief reasons for requiring these records are:

(1) To maintain such stocks as will meet the requirements of the production programme.

(2) To guard against fraudulent acts by employees.

(3) To provide a means of collating all the acts which occur incident to the movement of material and parts.

(4) To provide a means of ascertaining the financial status of the organisation's fluid assets.

The most convenient form of these records is that of the Stores Ledger, a form of which is shown in Fig. 5, p. 962. This should show at a glance:

(1) Quantity on order and order number.

(2) The acceptances into the stores of the material and parts, together with the detailed particulars as to date, order number on which supplied, and quantity.

(3) The issues from the stores together with the details as above.

(4) The balance of stock which remains at a given date after such transactions.

These forms are either bound together in loose-leaf book form or filed in card-index style. Further information which is given by the forms is:

(5) The minimum stock figure allowable.

(6) Parts or assemblies on which the material or part is used.

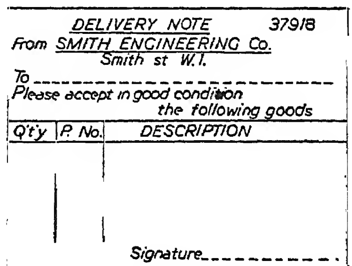


Fig. 32.—Delivery note.

Stores Layout

Principles of Layout.—The essential aims in laying out a stores should be:

(1) Location of stores of a particular kind near to the point where used.

(2) Accessibility in regard to size, bulk, quantity, and frequency of handling.

(3) Ability to expand when required.

(4) Placing of items in some prearranged order.

Location should be based upon the route of the items stored so that they are near to the point at which they are machined or assembled. This serves to cut down handling and in some cases aids in Production Control by breaking the types of items into a logical sequence. However, a balance has to be made of the possible extra stores labour involved against the saving in handling.

Accessibility.—Each item should be considered in regard to its placing within its particular stores, on the following basis:

(*a*) Bulk, or difficulty, in handling.

(*b*) Number of times such items are handled.

(*c*) Quantity to be stored.

(*d*) Possibility of spoilage due to perishing, etc.

(*e*) Danger from piling through possible top-heaviness.

Naturally, those parts which are heaviest or bulky to handle should be located nearest to point of use. This also applies to those parts more frequently handled. Sufficient allocation must be made so that parts stored in largest quantities are accommodated with ease. Much time and labour may be wasted through the necessity for extra handling due to insufficient space being allocated in original layout. The piling of heavy parts should be undertaken only when this can be done with safety; say, if the parts have larger area of base relative to height.

Expansion.—Sufficient floor space for storage should always be allocated in the planning of the factory layout, as an increase in the numbers of items to be stored will cause great inconvenience and loss of time and labour. Too often do we find this trouble occurring, resulting in the storage of parts or material in all sorts of odd spaces, necessitating extra handling and sometimes spoilage through placing in unsuitable places. The possibility always exists of expansion upwards, but this always involves extra labour and invariably a danger hazard.

TIME AND MOTION STUDY: RATE-FIXING

Definitions

Time Study.—A scientific analysis of the methods, operations, and equipment used or planned in doing a piece of work, the development of the best method of doing it, and the determination of the time required to perform it.

Motion Study.—Dividing the work into the most fundamental elements possible, studying these elements separately and in relation to each other, and from the elements when timed building the method of least waste.

Rate-fixing.—The determination of the appropriate wages rate and incentives after allowances have been made for unavoidable losses, such as fatigue, delays, equipment breakdowns, wearing of tools, etc.

Job Standardisation.—The determination of the one best way and standard time for performing a job under the available conditions, recording the correct procedure and time allowed on an appropriate operation instruction card.

Basis Time.—Time selected from study to cover the complete cycle of movements in the operation.

Task Time.—This is the time given to cover the base time and all the necessary allowances.

Observed Time.—That found by Time or Motion Study when making the observation. It may include errors and irrelevancies which have to be adjusted in choosing the Basis Time.

Methods of Arriving at Basis Time

Averaging the Times, i.e. taking an average of the times found.

Minimum Time Method.—Selecting only the minimum times for the constituents found in the Time Study and building the Basis Time from these.

Modal Method.—Using only the most frequently occurring times.

Median Method.—Using the middle time when placing them in a series in order of size.

Statistical Method.—Eliminates the obviously high or low values, averages the remainder for each elementary movement, and divides this average by the lowest figure accepted, thus indicating how far the average time exceeds the best times, giving the rate of deviation. Each elementary time is treated thus. Initiated by Merrick.

Levelling.—Setting a value for effort, skill, and consistency for the operator and of condition for the machine, and equating these values to the averaging method.

Advantages and Disadvantages of Each Method

Averaging the Times gives basis time rather higher than necessary unless all the allowances are adequately covered.

Minimum Method is the logical method, but gives times of rather low value unless good allowances are given.

Modal Method gives good reliable time when all proper allowances are also given.

Median Method is similar to averaging the times and has the same disadvantages.

Statistical Method gives very reliable results when correct allowances are added.

Levelling Method, the best method as this takes into account the relative personal attributes of the person observed, and thus provides a time suitable for any other operator.

Constituent or Manipulating Times cover the chief parts of a cycle of elementary operations; they are those such as turning over drill jig, raising and lowering drill into bush, etc.

Relation between Time and Motion Study

Time Study	*Motion Study*
Uses stop-watch to study simple motions.	Uses micro-chronometer and motion pictures.
Requires less highly specialised experience.	Emphasises importance of studying most elementary movements.
Is easier to use in shop.	Requires means of automatically recording time and motion. Preferably laboratory.
Is sufficiently accurate for most practical purposes.	Provides a means of studying methods and physical and mental attributes of operator.
Analyses conditions as they exist.	Provides data for improvement of methods and conditions of working and work-place.
Records sufficiently reliable for future purposes of building times.	Records may be used to analyse movements for future study. Records provide useful means of imparting teaching of methods. Knowledge of motions and times for motions provide useful means of accurate building of times for estimates. Covers all aspects of job—physical and psychological.

Therbligs.—Name given to fundamental elementary movements.

Synthetic Times.—These are built by use either of recorded data or time studies, to form the best to suit the job in hand.

Methods of Timing

Continuous Timing.—Watch is kept continuously running and time of commencement of each elementary movement is recorded.

Click-back Method.—Watch is started at each commencement of an elementary movement and stopped when it is completed. Useful for times of short duration.

Dual Element Timing consists in subtracting for two elementary movements the observed time for the longer, thus obtaining time of short movement. Used for times of short duration.

Two-Watch Timing.—Two watches are used, one to record overall times and elementary times by using a linkage for starting one watch and reversing the other.

Overall Timing of the operation may be used when it is not possible or necessary to discern between the elementary movements.

Allowances are given to cover extraneous circumstances by which the basis time may be exceeded when operation is proceeding.

Merrick gives the five most important, viz. fatigue, variation in rhythm, unavoidable delays, personal delays, machine delays.

Fatigue.—Defined as the effect of work upon an individual's mind and body which tends to lower his rate or grade of quality of production, or both, from his optimum performance.

Chief causes of fatigue :

(1) Environmental conditions of operator.
(2) Amount of sleep taken by operator.
(3) Physical requirements of the work.
(4) Mental requirements of the work.
(5) Conditions of work-place.
(6) Duration of working time.
(7) Monotony of job.
(8) Attitude of operator to supervisor and workmates.
(9) Danger hazards of job.

Fatigue allowances endeavour to cover such of the following above causes as are present in the operation, viz. 3, 7, and 9.

Unavoidable Delays are those which occur due to preparation for the job, trucking work, time booking, receiving instructions, training, etc., and are covered here under the heading of Preparation Times.

Personal Delays are those caused by the operator's own imperative personal requirements. Covered here by Personal Allowances.

Machine Delays occur in the respect of attendance to the machine during the operation, such as oiling, belt mending, starting, stopping, and tool sharpening. Should these delays be of long duration or frequent occurrence, the time thus taken should more rightly be recorded and assigned to some appropriate burden charge. Machine delays are combined with tool delays to form Machine and Tool Allowances.

Fatigue Allowances

Allowances given herewith are for average conditions of work-place in respect of ventilation, lighting, heating, noise, and cleanliness, unless otherwise stated.

	Per cent.
Drilling (including reaming, counterboring, countersinking, tapping with tapping head or vertical tapper) :	
Light work not requiring more than moderate physical or mental effort	8
Average for heavier work, component, and jig up to 15 lb.	12½
Heavy weight up to 30 lb. (including jig) and meticulous effort	20
Over 30 lb. with conveyor or gantry	30
Milling	
Light components in fixture	5
Heavy components up to 30 lb.	12½
Components over 30 lb. with conveyor or gantry	20
Centre Lathe	
Bar work up to 2 in. Simple operation	7½
,, 2 in. to 6 in. Production work	12½
,, over 6 in. Production work	20
Machine on plain work, average allowance	10
Castings, etc., up to 7 lb.	7½
,, 7 to 15 lb.	15
,, 15 to 30 lb.	30
Capstan or Turret Lathe.—Similar to centre lathe above.	
Grinding Machine.—Good average values	7½–10
Press Work	
(Power Press) Light components, short runs	15
long runs	10
Heavy components, short runs	25
long runs	15
(Fly Press) Good average value	25

	Per cent.
Shaping	
Light components up to 10 lb.	10
Heavier components up to 30 lb.	20
More intricate work—add	5
Broaching.—Good average value	10
Planing.—Good average value	12½
Assembly Work	
Light bench work, operator sitting, work-place well designed	5
Ditto, operator standing	7½
Riveting Machine.—Good average value	10
Heavy Work.—Sawing, metal, or wood	25–50
Fitting, etc.	
Filing, rough	50
Filing, finish	25
Scraping, flat surfaces, according to size	10–25
Scraping, bearings	15–20
Lifting, continuous through working period	50
Digging	50
Heavy labouring, coal heaving, etc.	50
Welding	
(Spot) Good average values: small to large components, thin to maximum thickness	15–20
(Oxy-acetylene) Good average values—short and long welds	15–25
(Butt and flash) Good average values—short and long welds	10–25
(Arc) Good average values—short and long welds	20–30
Cutting	
(Oxy-acetylene) Automatic	15–20
Manual	20–25
Finishing Processes	
(Spray painting) Good average values	15–20
Large areas and liability to be soiled by paint	20–25
(Polishing by Buff) Based on surface area	15–25
Work which becomes hot	20–30
Small, irregular surfaces	25
(Plating) All types	50
(Sand Blasting) Based on surface area	30–50

Note.—Processes above where percentage is based on surface area, the small areas have the greater percentage.

Allowances for Preparation Time

This varies with the following conditions:

(*a*) Form of time booking, clocking on, or issuing job card involved.
(*b*) Intricacy of instruction or degreee of familiarity with the job.
(*c*) Nature of job.

	Per cent.
General (for operators not setting machine)	
Average conditions for large batches and good work, card issuing system	2½
Under very good conditions	1
Maximum necessary for poor conditions and small batches	5

		Mins.
According to Job		
Drilling, **Reaming**, **Tapping**, **Counterboring**, **Countersinking**	Preparing machine, clocking on and setting machine	12
	For multi-spindle work, for each additional cutter add	2
	For multi-spindle work, for each additional jig add	3
Milling.—Preparing machine and clocking on		12

	Mins.
Centre Lathe	
Preparing machine and clocking on :	
up to 6 in. centre lathe	10
up to 12 in. centre lathe	15
heavy machines	20
Capstan or Turret Lathe	
Preparing machine and clocking on :	
up to 1 in. diameter bar	8
up to 2 in. diameter bar	12
over 2 in. diameter bar	15
Grinding Machine.—Preparing machine and clocking on	12
Shaping Machine.—Preparing machine and clocking on	12
Broaching Machine.—Preparing machine and clocking on	12
Presses.—Clocking on only (Preparation in the hands of setter—see "Allowances")	5

Setting Times

(Suitable either for operator setting or specialised machine setter)

Drilling **Reaming** **Counterboring** **Countersinking**	Setting machine, one tool and simple jig	8
	More intricate jig or accurate work	10
	Bulky jig or work	15
	Each additional tool	2
	Each additional jig	3
	Add for each clamping strap	5
Tapping		
Setting machine, one tap, work held in hand		8
	one tap, simple fixture	10
Add for more difficult fixture		3
Add for accurate threads (i.e. Herbert "F")		10
Milling (work held in vice, strapped to table or fixture)		
Setting machine	for first cutter, light work	20
	for pair cutters, light work not accurate	30
	for first cutter, medium work	25
	for pair cutters, medium work not accurate	35
	for first cutter, heavy work	35
	for pair cutters, heavy work not accurate	40
Milling (work held in dividing head or very accurate)		
Setting machine	for first cutter, light work	35
	for pair cutters, light work	45
	for first cutter, medium work	45
	for pair cutters, medium work	50
Add :	for each clamping strap	5
	for rotary table, hand feed	15
	for rotary table, power feed	20
	for high-speed head	40
	for vertical head	60
	to straddle milling for accurate work	5
Turning		
Setting machine, i.e. bar into chuck and setting cut :		
up to 6 in. centre lathe		10
up to 12 in. centre lathe		15
heavy machines		25
Setting gears for screwing (including calculations) :		
simple train		12
compound train		30
—(no calculations) :		
simple train		8
compound train		15

Other times are covered under "Manipulating Times."

Turret or Capstan Lathe

	Min.
Setting machine	
up to 1 in. diameter bar, general	15
add per tool	4
up to 2 in. diameter bar, general	20
add per tool	4
over 2 in. diameter bar, general	20
add per tool	6

Grinding Machine

Setting time—Small machine	10
Medium machine	15
Changing wheel—Small machine	15
Medium machine	20
Fixing steady—Small machine	5
Medium machine	8
Setting table for tapers—Small machine	10
Medium machine	15

Shaping Machine

Setting time—Vicework. Each surface	10
Work clamped to plate. Each surface	15

Broaching Machine

Setting time—3-ft. machine. Hole broach	15

Presses

Setting times dependent upon following factors:
(a) Bulk, i.e. size and weight of tool.
(b) Condition of tool.
(c) Adjustments for load, i.e. pressure pads as in bending or drawing tools.

Power Presses

In general, for straightforward tools allowances are:

Tools weighing up to 30 lb.	20
Tools weighing up to 60 lb.	30
Tools weighing up to 1 cwt.	40
Tools weighing up to 2 cwt.	50
Tools weighing up to 4 cwt.	60
Tools weighing up to 10 cwt.	75

For tools above 60 lb. two or more men will be required, in some cases to merely place tool on to bed of press and in others to aid in setting.

Greater allowances are required for tools of the non-pillar type.

Fly Presses

Simple blanking, pillar type, good condition	10
Simple blanking, non-pillar type, good condition	20
Simple bending, good condition	10
Complex bending, good condition	20

Machine and Tool Allowances

Drilling (machine in good condition)	*Per cent.*
(a) Light work (bar parts up to 2 in. diameter and up to 5 in. long)	5
(b) Medium work (bar parts over 2 in. diameter and up to 5 in. long)	7½
(c) Heavy work (castings over 8 lb.)	10

Reaming

Allowances as for drilling when limits over plus or minus 0·005 in.

Limits closer than above, up to plus or minus 0·001 in., add in each case above (a) (b) (c)	2½
Very close limits, add in each case above (a) (b) (c)	10–15

Tapping.—Increase drilling allowances by 2½ per cent. in each case, but for very good conditions no increase necessary.

Milling.—Allowances as for reaming.

Grinding.—Allowances as for reaming.

Presswork *Per cent.*

A wide divergence of the types of tools is likely in this group. For very poor conditions for machine and tool allowance, i.e. machine maintenance high and tool of poor design 25

Good average conditions however 10

Centre Lathe

Machine in good condition and skilled operator .. .. $7\frac{1}{2}$

Machine in good condition and unskilled operator .. .. .. $12\frac{1}{2}$

Capstan or Turret Lathe.—For each main cutting tool but not bar stop, centre drill, ending tool, etc. .. .. $2–2\frac{1}{2}$

For each machine a capacity chart should exist on which is given the necessary allowance for each class of work carried out thereon. This should be modified as conditions require; that is, as machine wears or is repaired.

Constituent or Manipulating Times

Loading Times

Drilling (loading drilling jigs)

This operation usually consists of picking up the component, inserting into the jig, and clamping.

These times vary with the type of jig, i.e. in respect of the method of loading, locating and clamping, and of unloading the part and the bulk of the part being machined. Types are numerous but main divisions are indicated below:

(A) Template, no clamping, part held by hand.
(B) Simple location, clamping by thumb screw.
(C) Simple location, clamping strap and thumb screw.
(D) Simple location, nutcracker clamp.
(E) Simple location, cam clamp.
(F) Simple location on spigot with pin fastening through existing hole in component and through spigot.
(G) Complex location.

Times given below account for each of the above for parts of varying bulk.

Times in Seconds

Type of Jig	(1) *Component up to 2 lb.*	(2) *Component up to 8 lb.*	(3) *Component over 8 lb.*
(A)	7	12	18
(B)	12	18	25
(C)	15	22	40
(D)	7	12	16
(E)	5	10	15
(F)	5	8	15
(G)	Add to each above times that found necessary for location.		

To each of the above times in column (3) must be added an allowance when the part is unwieldy.

Milling (loading milling fixtures)

This operation usually consists of picking up component, inserting into fixture, and clamping.

Fixtures are of great variety of types but have similarity to drilling jigs. Main types are given below:

(A) Vice with false jaws to form location.
(B) Fixture with thumb screw and clamping strap.
(C) Fixture with bolt clamping.
(D) Dividing-head type with collet grip.
(E) Fixture with cam clamp.
(F) Light work, part operated through bush.

TIMES IN SECONDS

Type of Jig	*Component up to 2 lb.*	*Component up to 8 lb.*	*Component over 8 lb.*
(A)	7	14	22
(B)	15	22	40
(C)	20	25	30
(D)	7	12	18
(E)	5	10	15
(F)	4	—	—

Centre Lathe

Chucking Times

(A) Bar up to 2 in. diameter, undo chuck, take forward required length and do up chuck.

(B) Bar up to 6 in. diameter, undo chuck, take forward required length and do up chuck.

(C) Already-turned castings, three-jaw, self-centring.
(D) Rough castings, three-jaw, self-centring.
(E) Rough castings, four-jaw, independent.

TIMES IN SECONDS

Type of Jig	*Component up to 2 lb.*	*Component up to 8 lb.*	*Component over 8 lb.*
(A)	8	—	—
(B)	16	—	—
(C)	20	40	80
(D)	12	30	60
(E)	40	80	140

Faceplate Work

(A) Component held in fixture, usually with simple location and strap clamp.

(B) Component held in fixture, usually with simple location and strap clamp but truing the component required.

(C) Component not held in fixture but clamped to faceplate. Requires truing.

TIMES IN SECONDS

Type of Jig	*Component up to 2 lb.*	*Component up to 8 lb.*	*Component over 8 lb.*
(A)	25	40	60
(B)	45	60	80
(C)	90	120	180

Add 15 seconds for each clamp over the first.

Unloading times for all the above can be considered as two-thirds loading time in each case. Well-designed jigs and fixtures should allow for easy ejection of the component.

Miscellaneous Manipulating Times

		Secs.
Drilling	*Bushes:* Place loose bush into jig	4
Tapping	Remove bush from jig	2
Reaming	*Jig:* Slide jig from spindle to spindle	2
Countersinking	Slide jig from last to first station	3
Counterboring	Turn jig on to other face	3–5
	Maximum for excessive weight	15
	Clean by blowing with air maximum	7
Cutter:		
	Place drill in chuck (quick change)	3
	Place drill in chuck (key type). This does not include starting and stopping machine	15
	Lowering drill into work	2–3
	Raise drill from work	2
	Move drill from bush to bush	2–3
	Clearing swarf from drill when drilling deep holes (three times diameter)	2
	Grinding drill: Add 3 per cent. to basis time when not covered in tool allowance.	
	Exchange drill (includes starting and stopping machine and exchanging drills from chuck)	25
Chuck:		
	Fit chuck into spindle	5–7
	Remove chuck from spindle	10–14
Milling		
Cutter:		
	Approach to job from loading position	2–5
	Return after cutting—lever	2
	screw	12–18
	power	as available
	Overrun—slab cutters, $\frac{1}{4}$ in.	
	end mills, $\frac{1}{8}$ in.	
	face cutters, $\frac{1}{4}$–$\frac{5}{8}$ in. (According to diameter)	
Indexing		3–5
	For long arcs and clamping	6–10
Centres:	Work between centres, see "Centre Lathe."	

Centre Lathe

Tool Post:	*Secs.*
Put on Armstrong-type tool holder	30
Put in and adjust tool for Armstrong-type holder	20
Index square tool post	8–16
Put in and adjust each tool for square tool post	40
Chuck:	
Exchange chuck for faceplate—small	120
medium	200
Exchange face for chuck—small	90
medium	150
Machine:	*Secs. per ft.*
Wind saddle along bed	6
Wind slide rest to work	10
	Mins.
Fixing steady rest to machine	8–12
Setting steady rest to size	2–5
Setting over slide rest for taper cut	3–7
Centres:	*Secs.*
Clean and insert centres—per pair	30–45
Put on carrier—small	8
medium	10
Grease work—small	5
medium	7
Place between centres—small	6
medium	10
Adjust tailstock—small	4
medium	7
Presswork on mandrel—small	12
medium	18

(Above includes walking to and from mandrel press at reasonable distance.)

Tailstock: Clamping tailstock in new position	2–5

Capstan and Turret Lathe

Bar:	Insert bars into machine up to ¾ in. diameter	40–90
	¾ in.–1½ in. diameter	120
	1½ in.–2 in. diameter	180
	2 in.–4 in. diameter	240–300
Feed bar to stop up to 2 in. long or maximum capacity of machine.	By hand—¾ in. diameter	2
	1½ in. diameter	3
	2 in. diameter	6
	4 in. diameter	15
	By lever-trip mechanism—¾ in. diameter	1
	1½ in. diameter	2
	2 in. diameter	4
	By air—¾ in. diameter	up to 1
	1½ in. diameter	up to 2
	2 in. diameter	up to 2
Collet:		
Insert parts into collet (with machine running and no truing necessary)	small	3
	medium	6
	large	8
If truing necessary—	small	up to 6
	medium	up to 9
	large	up to 12

Capstan or Turret Head

		Secs.
Run up turret head to commence cut	$\frac{3}{4}$ in. diameter	1
	$1\frac{1}{2}$ in. diameter	$1\frac{1}{2}$
	2 in. diameter	$1\frac{1}{2}$
	4 in. diameter	2
Rotate turret head—one hole		2–4
two holes		4–6
three holes		6–8
four holes		7–9
five holes		8–10
six holes		10–11
Elapsed Movements: Between machine manipulation		1
Cross Slide: Take cross slide to work		2
Manipulation on No. 7 Ward Capstan:		
Stop machine, unload and load gunmetal casting (3 lb.) into boring fixture (easy location), do up three clamps and start machine		32
Stop machine, unload and load gunmetal casting (3 lb.) on angle bracket, locate on two pins and central spigot, clamp with C-washer (easy location) and start machine		20
Stop machine, unload and load iron casting, locate between pins on faceplate, do up two clamps and start machine		30
Manipulation on No. 0 Brown and Sharpe Capstan:		
Load part into collet, using pilot in turret, close collet and start machine		5
Stop machine and unload part from collet		3
Stop machine, unscrew part from adapter, screw in fresh part, tighten with key and start machine, thread O B × $\frac{5}{16}$ in. long		15
Load part into collet and close collet, machine running continuously, $\frac{1}{4}$ in. diameter × $\frac{5}{16}$ in. long		3

Grinding (loading and unloading times as for Centre Lathe)

Wheel:		*Mins.*
	Changing wheel (already on adapter)	7
		Secs.
	Dressing wheel	40–60
	Winding to work	up to 5
Tailstock:	Clamp tailstock in new position	up to 5
Work on Mandrel:	As Centre Lathe.	
Work between Centres:	As Centre Lathe.	
Magnetic Surface Plate:		
	Loading parts and magnetising	up to 5
	Demagnetising and unloading parts	up to 7
		Mins.
Steady Rest:	Fixing to machine	8
	Setting to size	2

Power Press: *Strip*

		Secs.
Hand feed	Insert—narrow to medium	10–15
	heavy or wide	20–30
	Reverse strip	15
	Remove from die	18
	Oil strip	6–10
	Fold strip	10
	Tie strip	18
Roll feed	Insert—narrow to medium	10–15
	Remove from die	10
	Oil strip	18
	Fold strip	10
	Tie strip	18

	Secs.
Insert Pressings into Die (bending, drawing, etc.)	
Small components, 5 in. × 5 in.	2–3
Medium components, 12 in. × 12 in.	6–10
Large components, 4 ft. × 4 ft.	12–15
Poor location, add	3–7
Heavy gauge, add	2–5
Subsequent Drawing Operations	
Insert drawing into die—small	2–4
medium	6–10
large	12–16
Removing from Die	
Work pushed through die—small components	2–4
medium components	5–8
maximum	16
Some tools will have automatic ejection, therefore place down only necessary, say	1

Fly Press

Insert Pressings into Die: as above.	
Removing from Die: Good tools	1
(increase for tight location)	
Some tools will have automatic ejection, therefore place down only necessary, say	1
Time per Swing: Small to heavy	1–8
Planishing: Insert, planish, and place down	4–6

Assembly

Light Assembly—Good Average Values

	Secs.
Screws	
Pick up first piece and place in fixture	4–7
Place each subsequent piece in position	2–4
If parts are good fit	3–5
Average small screws up to $\frac{1}{4}$ in. diameter, up to $\frac{5}{16}$ in. long:	
(1) Pick up, insert and start by hand	4–6
(2) Pick up, insert and tighten—spiral	10–12
ratchet	12–16
ordinary	15–19
electric	8
Screws up to $\frac{5}{16}$ in. diameter:	
(1) Pick up, insert and start by hand	6–8
(2) Pick up, insert and tighten, add 25 per cent.	
Pick up small part in left hand, gasket in right hand, place in tray, insert three screws in holes with standard clearance	12
Place above sub-assembly on to float chamber and tighten three screws with electric screwdriver (screws 4 B.A.)	21
Assemble spring on to adjusting screw and hand screw into boss (screw 0 B.A.)	5
Assemble needle valve to body and tighten with hand brace ($\frac{1}{8}$ in. gas)	9
Pins, etc.	
Pick up, insert into hole, hammer into position one pin 1 in. long × $\frac{1}{8}$ in. diameter	7
Pick up, insert into hole, hammer into position two drive plugs (one $\frac{1}{4}$ in. diameter, one $\frac{1}{8}$ in. diameter), each $\frac{1}{4}$ in. long	16
Pick up, insert into hole, hammer into position four plugs (three $\frac{1}{4}$ in. diameter and one $\frac{1}{8}$ in. diameter), each $\frac{1}{4}$ in. long	21
Pick up, insert and open out split-pins	9–18
Nuts	
Tighten with box spanner up to $\frac{3}{8}$ in. Whit.	6
Tighten with flat spanner up to $\frac{3}{8}$ in. Whit.	8
Tighten with electric nut driver up to $\frac{3}{8}$ in. Whit.	3
Studs: Up to $\frac{1}{4}$ in. with stud driver	10

Gauging Times

The times given include picking up the gauge, using the gauge and placing down.

Snap Gauge

Up to 1 in., fine limits, 7 secs.; medium limits, 3 secs.
1 in. to 3 in. ,, ,, 10 ,, ,, ,, 5 ,,

Plug Gauge

Up to ½ in. ,, ,, 5 ,, ,, ,, 2½ ,,
1 in. to 2 in. ,, ,, 7 ,, ,, ,, 4 ,,
2 in. to 3 in. ,, ,, 10 ,, ,, ,, 5 ,,

Profile Gauge

Up to 1 in. length, fine limits, 5 secs.; medium limits, 3 secs.
1 in. to 3 in. ,, ,, ,, 7 ,, ,, ,, 5 ,,
3 in. to 5 in. ,, ,, ,, 12 ,, ,, ,, 8 ,,

Screw Plug Gauge: medium length, 30 secs.; long length, 60 secs.

Screw Ring Gauge: medium length, 25 secs.; long length, 45 secs.

Wickman-type Gauge

Up to $\frac{5}{16}$ in. diam × ½ in. long = 2½ secs.; 1 in. long = 3½ secs.
$\frac{5}{16}$ in. — $\frac{7}{16}$ in. diam. × ½ in. long = 3 ,, 1 in. ,, = 4 ,,
½ in. diam. × ¾ in. long = 3½ ,, 1½ in. ,, = 5 ,,

Personal Allowances

These vary with conditions and will be low where ample rest pauses are given. Where batches are large and conditions good, allowance may be as low as 1 per cent but under moderate conditions 2½ per cent. will be found suitable. This allowance should rarely exceed 7½ per cent. under worst conditions.

Allowances for Small Quantities

VARIABLE RHYTHM

Quantity:	1–3			4–10			11–25	
Floor to Floor Time (Mins.)	*Easy* %	*Normal* %	*Difficult* %	*Easy* %	*Normal* %	*Difficult* %	*Normal* %	*Difficult* %
3	15	50	80	5	15	50	5	15
5	10	40	65	5	10	40	3	10
7	7	35	55	3	5	35	2	7
10	5	30	50	—	3	25	—	5
12	3	22	40	—	2	20	—	3
15	—	15	25	—	—	15	—	—

Above allowances are in addition to all other allowances given.

Compensation given based upon:

(*a*) Number on Works Order.
(*b*) Similarity to jobs already made.
(*c*) Difficulties of skill or fatigue involved.
(*d*) Calculated time required per piece.

CALCULATION OF MACHINING TIMES

Drilling.—Time for drilling to depth D, in minutes

$$= \frac{\text{Spindle speed in r.p.m.}}{\text{Feed per revolution}} \times D$$

or Feed per minute $\times$ D.

Reaming.—Calculations as for drilling.

Cutting speed is most suitable at half the speed for same diameter as for drilling.

Feed can be up to $2\frac{1}{2}$ times drilling feed.

Reamer will travel beyond taper lead in cutting through holes, i.e. up to $\frac{3}{16}$ in. longer than nominal depth.

Tapping.—Times given below are for tapping standard depths of holes.

TIME IN SECONDS

Diameter of Tap	*Cast Iron*	*M.S.*	*Aluminium*	*Brass- or Zinc-base Alloy*	*High-tensile Steel*
$\frac{1}{8}$	5	6	3·5	4	6
$\frac{1}{4}$	8	10	4·5	6	12
$\frac{5}{16}$	9·5	12	5·5	7	15
$\frac{3}{8}$	11	14	6·5	8	18
$\frac{7}{16}$	12·5	16	7	9	21
$\frac{1}{2}$	14	18	8	10	24
$\frac{9}{16}$	15·5	20	9	11	27
$\frac{5}{8}$	17	22	10	12	30
$\frac{3}{4}$	20	26	11	14	36
$\frac{7}{8}$	23	30	12	16	42
1	26	34	14	18	48

Above times include manipulating and gouging but do not include for loading and unloading jig.

Milling.—Cutting time for a given length L, in minutes, where

A = Approach from loading position = 0·03 to 0·1 mins.
S = Distance travelled to start cut = $\sqrt{d(D-d)} + \frac{1}{4}$ in.
O = Overrun at end of cut = $\frac{1}{4}$ in. to $\frac{1}{2}$ in.
F = Table speed in inches per minute.
D = Diameter of cutter.
d = Depth of cut.

$$\text{Cutting Time (minutes)} = \frac{S + L + O}{F} + A$$

$$= \frac{(\sqrt{d(D+d)} + \frac{1}{4}) + L + O}{F} + A.$$

Turning.—Time to cut length L inches per cut in minutes. D = diameter to which bar is to be reduced.

$$= \frac{\text{Spindle speed in r.p.m.} \times L}{\text{Feed per revolution}}$$

$$\text{or } \frac{\text{Number of cuts per inch} \times L}{\text{r.p.m.}}$$

$$\text{or } \frac{\pi D}{12} \times \frac{L}{\text{Feed per revolution} \times \text{cutting speed}}$$

PERMISSIBLE AREA OF CUT AT VARIOUS SPEEDS

Area of Cut (sq. in.)	*Cutting Speed (ft. per min.)*			
	M.S.	*High-tensile Steel*	*Cast Iron*	*Brass*
0·001	130	95	60	200
0·002	115	75	57	175
0·003	100	60	55	150
0·004	90	50	50	135
0·008	80	40	45	120
0·016	60	35	35	100

For free-cutting brass or M.S. increase speeds 50 per cent.

Parting Off

TIMES FOR PARTING OFF ROD IN SECONDS

Diameter	*F.C. Brass*	*F.C.M.S.*	*M.S.*	*Copper*	*Cast Iron*	*Brass*
Up to $\frac{1}{4}$	3	5	7	5	10	5
$\frac{3}{8}$	4	7	10	8	17	7
$\frac{1}{2}$	5	9	13	10	22	8
$\frac{5}{8}$	7	11	16	13	28	9
$\frac{3}{4}$	10	14	20	16	33	10
$\frac{7}{8}$	11	17	24	20	40	12
1	12	20	28	23	46	14
$1\frac{1}{4}$	15	23	33	27	54	18
$1\frac{1}{2}$	18	28	40	32	62	22
2	22	35	52	46	70	26

Times allow for run up and return of cut-off slide or compound rest.

Grinding.—Time to grind depth D

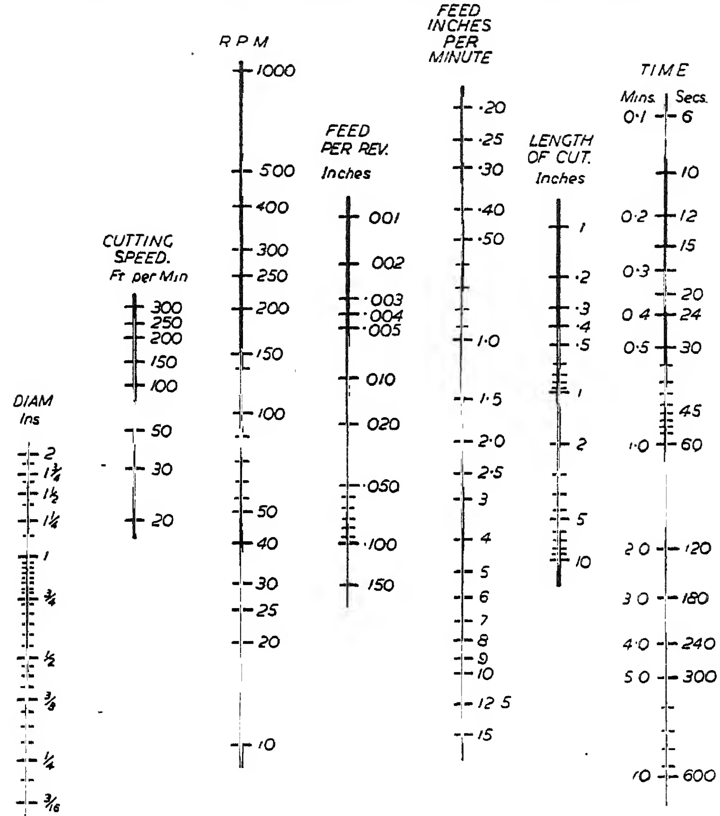
$$= \frac{\text{Grinding allowance}}{\text{No. of passes required per min.} \times \text{feed per pass}}.$$

Number of passes required $= \dfrac{\text{r.p.m.} \times W \times \frac{2}{3}}{L - W + 1}$

where W = Width of grinding wheel.
L = Length to be ground.

The Nomogram on p. 997 is a ready means of ascertaining cutting speeds, feeds, and times for given lengths of work.

NOMOGRAM FOR ASCERTAINING CUTTING SPEEDS



To Find Cutting Speed (peripheral speed) of ½-in.-diam. bar at 300 r.p.m.

Place rule to connect ½-in. diam. with 300 r.p.m., and cutting speed will be seen to be 39 ft. per min.

To Find Cutting Feed—(*a*) When travel in inches per minute is given:

Place rule against reading for spindle speed (say, 300 r.p.m.), connect with travel (say, 1 in. per min.), and feed will be found to be 0·003 in. per rev. (approximately).

(*b*) When feed per revolution is given:

Place rule against reading for spindle speed (300 r.p.m.), connect with feed (0·020 in. per rev.), and read travel 6 in. per min. on appropriate scale.

To Find Time to Make Cut when length of cut is 5 in. and travel 6 in. per min.: Place rule against scales for length of cut and travel, and time for cut will be found at 50 secs,

MOTION STUDY

Definitions, etc., of the Therbligs

Below are given the designation, abbreviation, symbol, and definition of each of the Gilbreths' original 18 therbligs.

Therblig	*Abbreviation*	*Symbol*	*Explanation of Symbol*	*Definition of Therblig*
(1) Search ..	Sh		Eye turned as if searching.	Searching or groping for object.
(2) Find ..	F		Eye straight as if fixed on object.	End of search.
(3) Select ..	St		Reaching for object.	Choosing one object from among others.
(4) Grasp ..	G		Hand open for grasping object.	Taking hold of object.
(5) Transport loaded.	TL		Hand with object in it.	Moving object from one place to another.
(6) Position ..	P		Object being placed by hand.	Pulling object into place.
(7) Assemble ..	A		Several objects put together.	Place one object on to or into another to form assembly.
(8) Use	U		Word "use."	Make use of object, start cut, manipulate tool.
(9) Disassemble	DA		One part of assembly removed.	Separate one object from another.
(10) Inspect ..	I		Magnifying glass.	Test to determine suitability.
(11) Pre-position	PP		A nine-pin set up in a bowling alley.	Place in predetermined position.
(12) Release load	RL		Dropping contents out of hand.	Letting go of object in given position.
(13) Transport empty.	TE		Empty hand.	Movement of the empty hand in reaching for object.
(14) Rest for overcoming fatigue.	RE		Man seated as if resting.	Factor allowed to permit work to overcome fatigue from work.

DEFINITIONS, ETC., OF THE THERBLIGS—*continued*

Therblig	*Abbreviation*	*Symbol*	*Explanation of Symbol*	*Definition of Therblig*
(15) Unavoidable delay.	UD		Man bumping his nose unintentionally.	Delay in movement caused by one member resting during operation.
(16) Avoidable delay.	AD		Man lying down on the job intentionally.	Delay caused by the worker for which he is responsible.
(17) Plan ..	Pn		Man with finger at brow thinking.	Mental reaction preceding further action.
(18) Hold ..	H		Magnet holding bar.	A form of grasp in which a secondary factor or tool may be used.

SOME EXPLANATIONS AND TIMES FOR THERBLIGS

Search.—Should be minimised as far as possible. Is mostly carried out by the eyes. It is difficult to give definite times for this as it is mostly of very short duration in properly planned work-place.

Find.—Is really most of above therblig and occurs at its end. It is mostly a mental reaction of very short duration.

Select.—Is again of very short duration and as far as possible should be eliminated by the design of the work-place. Various aids of shape, size, or colour might be used to minimise it where necessary.

Grasp.—Is affected by the size and shape of the object, the position from which it has to be taken and the possibility of an aid such as a tool.

	Secs.
For picking up washer from flat surface :	
$\frac{1}{8}$ in. thick by sliding and pinching	0·2
$\frac{1}{16}$ in. thick by embracing with fingers	0·25
$\frac{1}{4}$ in. thick by sliding and pinching	0·15
$\frac{1}{4}$ in. thick by embracing with fingers	0·2
For picking up pins from flat surface :	
$\frac{1}{16}$ in. diameter × $\frac{1}{2}$ in. long, sliding and pinching	0·35
For picking up washer from bin at work-place :	
up to $\frac{3}{4}$ in. diameter	0·6
For picking up casting from work tray at side of operator :	
With one hand. Casting, 8 in. diameter. Easy reach	1·02
With two hands. Casting, 8 in. diameter. Maximum reach ..	1·7
For picking up casting from stack on bench in front of operator :	
Casting, 8 in. diameter. Easy reach	0·7
For picking up small screws up to " 0 " B.A. or $\frac{1}{4}$ in. Whit. from bin at work-place	0·5

Transport Loaded } **Transport Empty** } The time for these two therbligs is affected by the distance through which the hand has to move. Experiments show that the hand will travel faster through long distances than short. A portion of the time taken is, of course, used in stopping the movement, and on

short distances this forms a relatively greater portion of the time taken. The grasp therblig also affects the time of the transport therbligs. Where the part to be grasped is of a fragile nature or has projections affecting the form of grasp possible, this affects the action of the hand in coming to a stop. The possibility of eliminating these therbligs should be studied. This can be effected :

(1) where bulk handling is possible ;
(2) chutes lead the parts to the job.

For carrying washers, etc., a distance of 6 in. and placing down, 0·36 sec.
For carrying washers, etc., a distance of 12 in. and placing down, 0·40 sec.
For carrying washers, etc., a distance of 18 in. and placing down, 0·52 sec.

Pre-position
Position } The time for these therbligs is dependent upon the condition of the parts involved, in their relative fit and the possibility of providing means of arranging the part by some previous movement.

(*a*) Positioning pin in hole, very close fit, 0·002 in. clearance, 0·3 sec.
(*b*) Positioning pin in hole, loose fit, 0·012 in. clearance, 0·15 sec.

	Secs.
Hole has 90 degree countersink in both above cases :	
as (*a*) but 60 degree countersink on hole	0·33
as (*b*) but 60 degree countersink on hole	0·18
as (*a*) but no countersink, hole parallel to end	0·5
as (*b*) but no countersink, hole parallel to end	0·4
(*c*) Positioning link over two pins, clearance 0·004 in.	0·44
(*d*) Positioning link over two pins, clearance 0·012 in.	0·30
Pins have square ends and are of equal length :	
as (*c*) but pins have spherical ends	0·17
as (*d*) but pins have spherical ends	0·12
as (*c*) but screws instead of pins	0·48
as (*d*) but screws instead of pins	0·37
Position washer over screw, standard clearance	0·66
Position casting in rectangular location	1·20
Position screw in hole (preparatory to turning for tightening)	1·10
Position nut on screw, free area	1·10
Position nut on screw, limited area	1·50
Position round meter cover over base, clearance 0·005 in.	2·50
Position screwdriver in screw slot	1·15

Wherever possible tools should be pre-positioned.

In using a screwdriver suspended by helical spring approximately over the screwing position, a saving of 16 per cent. in time is made as against picking up a screw from the bench.

Inspect.—Depends for its time duration upon the kind of inspection being made, i.e. the possibility of distinct differences and of using various aids to the physical and mental reactions in use, or transferring the inspection to a mechanical device. As guide to the effect of stimulus to the reaction time necessary for the individual, the following gives ratios of these times for various stimuli taken from a series of experiments :

Reaction after light flashed	450
Reaction after buzzer sounded	370
Reaction after a touch	350
Reaction after electric shock	280
Reaction from watching instructor's action	100
Reaction according to instruction to make choice	650

Inspectors should be chosen according to their ability to react to given stimuli and for good eyesight.

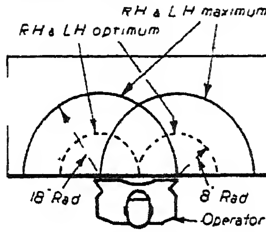
Release Load.—Occurs when the part in transport has reached the end of its travel. It should, in consequence, be of very short duration, or in fact be hardly discernible, the transport therblig giving place almost instantaneously to a position or use therblig.

Hold.—Occurs in assembly work and machine operating. No difficulty should be experienced in its elimination. The provision of fixtures, holding devices, or placing on bench is mostly very simple.

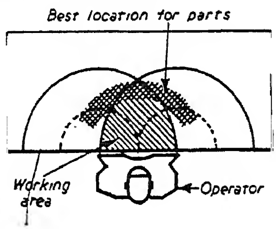
DESIGN OF THE WORK-PLACE

One of the essential lessons taught by Motion Study is the design of the work-place, and this provides means of ascertaining operators' physical attributes and data from which the work-place can be set out.

Working Area.—The figure shows the normal area over which the operator can be expected to work with each hand:



Layout of Work-place.—The planning of the area in which the operator is to work should take account of the parts to be used and the order in which they are to be taken to the assembly by either hand:



Elevation of Work-place

Height of bench, maximum 33 in. seated, 36 in. standing.

Height of seat, 24 in.–30 in.

Width of seat, 15 in.–18 in.

Depth of seat, 12 in.–14 in.

Height of back-rest, 5 in.–7 in. above seat, swivelled to accommodate operator's back.

Length of back-rest, 10 in.–13 in.

Width of back-rest, 4 in.

Some Economic Factors in the Design of the Work-place.—Arrangement of the containers and tools at the work-place should allow for circular movement, so that elementary operations in the work cycle are performed rhythmically and in natural order. Attention should be paid to the possibility of using both hands simultaneously. This tends towards rhythm, saves time, and eases fatigue.

Short rhythmic movements save up to 20 per cent. over long and less rhythmic ones.

Delivery of finished work by means of gravity chutes should be considered.

Minimum number of motions should be used.

Consideration should be given to the possibility of using the feet, such as for operating a clamp, whilst leaving the hands free.

The work-place should be designed to minimise the following movements, and thus obtain the savings given (as against enforced use of these movements):

Use of eyes for "inspect"	up to 25 per cent.
Use of eyes for disposing of finished work ..	up to 15 per cent.
Use of eyes for acquiring parts	up to 15 per cent.

Picking up parts from floor to bench height equals loss of up to 2 secs. per part.

Inspection is the fundamental aspect which controls quality.

The Aims of Inspection

(1) Ensures that product is to standard desired.
(2) Ensures that material used is of uniform quality.
(3) Provides means of ascertaining variations in manufacture.
(4) Provides means of discovering inefficiencies in manufacture.

(1) **Product to Desired Standard.**—In so far as inspection stands between the customer and the manufacturing unit, it determines that only the products desirable should reach the former. However, quality of goods being only commensurate with price that they will obtain, inspection has to be related to the standards thus set. Setting standards too high may result in goods which have no market because cost is too high.

(2) **Control of Quality of Material used.**—This is the primary aspect of inspection, so far as manufacture is concerned, and ensures that material of whatever kind shall be that desired for the purpose of aiding economic production and quality of finished goods.

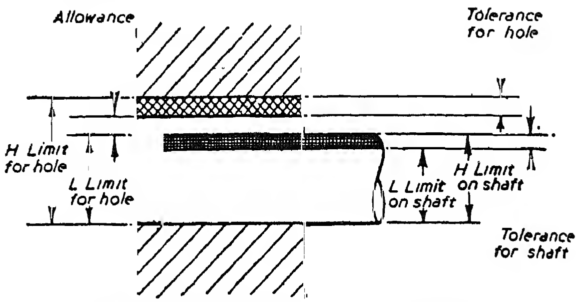


Fig. 1.—Nomenclature for dimensional standards.

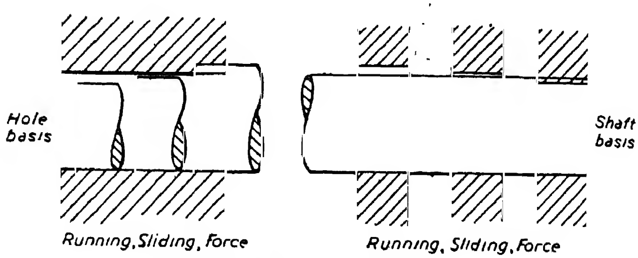


Fig. 2.—The bases of the limit system.

(3) **Ascertaining Variations in Manufacture.**—One of the chief benefits of inspection, when applied at various stages of the manufacturing process, is to check variations which occur as this proceeds. As applied to modern industry, inspection actually aids in providing increased output because bad work is found before large quantities are spoilt. This aspect of inspection provides the key to interchangeability.

(4) **Ascertaining Inefficiencies in Manufacture** results from the above

application, and where used to best purposes enables checks to be made of efficiency of supervision, labour, tools, plant, and machinery.

Quality and Uniformity.—Inspection should therefore aim at providing the two set standards of Quality and Uniformity. These two standards are required for the purpose of measuring the quality of the goods to the customer and manufacturer. They are embodied in the design and inspection provides the means of attaining them.

Inspection Standards are set as physical means of checking goods, such as tensile strength, electrical resistance, size, weight, hardness, etc. These are determined by the designs department according to the requirements of the goods and in relation to the price obtainable.

Raw Material Inspection.—The raw material for the goods, as determined by the designs department and given in some form of specification, is the first concern of inspection in the chain of manufacture. To-day most material for production is bought to a standard specification, whether manufactured metal, screws, nuts, bolts, chemicals, etc. In Great Britain the British Standards Institution is the central body which the Government and Industry have set up to provide the standards to which many raw materials and manufactured components shall conform. Much can be saved in both time and money by ordering to these standards where possible.

Three Inspection Standards by which all material or goods are checked :

(1) Physical properties.
(2) Finish.
(3) Dimensions.

Physical Properties are widely variable and depend upon the material or goods concerned, but in engineering are mainly those of strength, hardness, homogeneity, electrical resistance, and absorption. The organisation concerned has to determine for itself whether it will use the means available in checking these properties, which can be very expensive, or whether by purchasing from reputable firms to agreed standards the checking can be waived. However, for its own manufacturing processes these may be necessary where some part of the process affects the physical properties. For instance, in the heat treatment of many parts the properties are bound to be changed, and the new conditions require measuring to ascertain whether they conform.

Determining Physical Properties.—The following instruments are used for the determination of physical properties of materials :

Property	*Instrument or Machine*	*Measurement*
Tensile strength	Various tensile machines	Tons per sq. in.
Compressive strength	Various compression testing machines.	Tons per sq. in.
Torsion	Torsion testing machine.	
Shear	Punch test machine.	Tons per sq. in.
Bending	Transverse test machines.	
Hardness	Brinell ball test. Shore scleroscope. Abrasive tests.	Arbitrary numbers which have relation to yield point and ultimate strength.
Fatigue	Dynamic testing machines Impact machines.	Number of reversals before fracture at given loads.
Homogeneity	X-ray. Weight.	Freedom from cracks. Castings under certain weight are suspects for blow-holes.
Electrical resistance	Ohmmeter.	Ohms per unit length.
Electrical conductivity	Ammeter.	Amps. per unit area.

Standards of Finish.—These are less dependent on actual means of measurement than upon the individual judgment of the inspector and are accordingly less exact. However, aids do exist and are coming more into use.

Dimensional Standards are the more easily checked and are those which mostly concern inspection. They are the ones upon which most engineering works depend and one of the chief standards for interchangeable manufacture. The standards prescribed are based upon the requirements of the part in its functioning and the limitations imposed by the manufacturing process. Thus, for certain parts, the dimensional variations permitted vary with the job they have to do and the processes available. Both aspects are dependent upon each other. Thus, for a part to function in a certain way, the process has to be chosen which will give variations suitable to this functioning. Thus a hole in which a screw fits loosely need only be drilled with the limitations in machining which are attendant upon the drilling process. A hole which has to receive a pump plunger might be lapped because this process can be done with a narrower range of variations.

A **Standard Nomenclature** has been established to cover the various relations between the aspects of dimensional standards (see British Standard Specification No. 164). A selection from this Standard is given here (Fig. 1).

Dimension is a means of specifying size of part.

Nominal Size is that to which reference is made as a matter of convenience.

Basic Size is that to which reference is made when variations are considered. (Nominal and basic size may often be the same.)

Actual Size is that to which the part conforms when measured.

Limits are the extreme dimensions to which it is permissible for the considered size to go.

Tolerance is the difference between the two extremes of high and low limits for the size.

Allowance is the difference between the high limit for a shaft and the low limit for the hole which is to accommodate it within a given class of fit. An allowance is positive when there is clearance between the shaft and hole and negative when there is interference.

Fit expresses the relationship between the shaft and hole in respect of the play or interference which exists.

Clearance Fit exists when the largest shaft is smaller than the smallest hole. The allowance is therefore positive.

Interference Fit exists when the smallest shaft is larger than the largest hole.

Transition Fit occurs when the limits permit a fit existing between either of the above two cases.

Basis for Limit System.—In Great Britain it is common practice to use what is known as the hole basis for fixing the limit system of fits.

Hole Basis.—In this system the hole is the constant member, and the various classes of fits are obtained by varying the size of the shaft. The prime reason for using this system is that tools for cutting holes to size, e.g. the reamer, are best purchased on a standard size, and the variations made on the shaft, which can more cheaply be produced in a variety of sizes.

Shaft Basis.—In this system the shaft is the constant member, and the hole varies to give the class of fit. Fig. 2 shows the two bases of fit.

Unilateral System of Limits is that in which the low limit is the normal size of the hole and the high limit is given as a plus amount, thus:

$$\left.\begin{matrix} \text{H} & 1{\cdot}016 \text{ or} \\ \text{L} & 1{\cdot}000 \end{matrix}\right\} 1 \begin{matrix} +\ 0{\cdot}016 \\ -\ 0{\cdot}000 \end{matrix}$$

Bilateral System gives the limits as above and below the basic dimension, thus:

$$\left.\begin{matrix} \text{H} & 1{\cdot}008 \text{ or} \\ \text{L} & 0{\cdot}992 \end{matrix}\right\} 1 \pm 0{\cdot}008$$

The former system is the one recommended by the British Standards Institution.

Gauges are used to control sizes during manufacture.

A Gauge is a standard of measurement used to control the size of work. They are divided into two classes: workshop and inspection.

Workshop Gauges are used during manufacture in the machine shop by the works inspection organisation for the finished part.

Inspection Gauges are used for the acceptance of work by an external inspection organisation or customer.

Relationship between Workshop and Inspection Gauges.—Inspection gauges are made so that work which passes a correct workshop gauge will be accepted by the corresponding inspection gauge; thus the latter have a definitely wider tolerance (Fig. 3). This is intended to cover a margin of wear in the former.

"Go" and "No Go" Gauges.—Gauges are generally designed to have a means of measuring the high and low limits. For this purpose they are provided with "Go" and "No Go" portions. In measurement of holes the "Go" portion sets the low limit and the "No Go" the high limit. Thus the gauge known as a "plug gauge" has one end which must be accepted by the hole and the other end must not enter the hole. For shafts, the reverse is the case, the "Go" setting the high limit and the "No Go" portion the low.

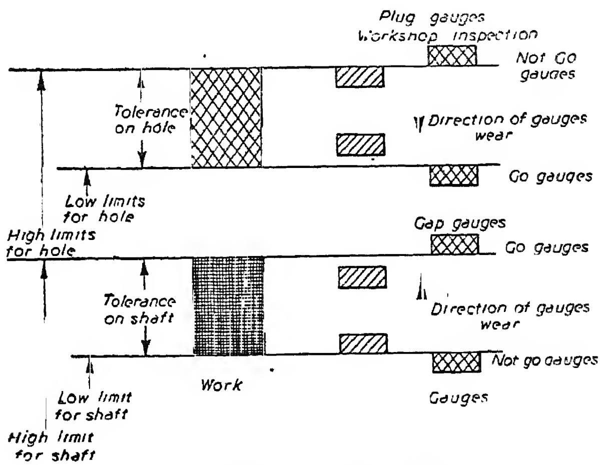


Fig. 3.—Tolerances on workshop gauges.

Organisation of Inspection.—Inspection is generally organised under the charge of a chief inspector.

Duties of Chief Inspector.—The chief inspector undertakes the following duties:

(*a*) Control of inspection department for discipline, organisation, and supervision of gauges.

(*b*) Final decision as to variations that can be made from standards set.

(*c*) Salvaging of defective work where possible to minimise loss and waste.

(*d*) Supervision of testing laboratories where these exist.

Inspection Personnel usually consists of skilled inspectors, unskilled viewers, and clerical labour for routing purposes.

Skilled Inspectors are generally able to use all forms of measuring tools, have a knowledge of the processes undertaken and ability to decide arbitrary cases.

Unskilled Viewers are generally trained to use limit gauges, but have no ability to decide outside these tools.

Clerical Labour is required to deal with personnel matters, statistical work in connection with production department requirements and control of quality,

card indexing of gauges, etc. The inspection department is often required to furnish statistical matter required for dispatch of work and routing.

Relationship of Inspection to Management.—This has always been a vexed question. The person to whom the chief inspector is responsible varies considerably throughout industry. We find the following as examples:

(*a*) To general manager.
(*b*) To chief engineer.
(*c*) To works manager.
(*d*) To sales manager.
(*e*) Independent status where responsibility is to Board of Directors or Managing Director.

The advantages and disadvantages of each class of responsibility are:

(*a*) *Advantages:* An independent status which overcomes objections of interference with the inspection function by those with vested interests (see *b* and *c*).

Disadvantages: May cause aggravation where design and production functions are overridden.

(*b*) *Advantages:* Chief engineer, as being responsible for design, has good knowledge of requirements of the product, therefore deviations from set standards may rightly be submitted.

Disadvantages: When chief engineer is responsible for design, ability to override inspection may result in concealing defects in design. Inspection being also a means of checking manufacturing standards when responsibility is to chief engineer, this may cause friction as an implied criticism may be felt.

(*c*) *Advantages:* As inspection is carried out within the precincts of the works, responsibility of works manager for all labour so employed is implied and discipline necessary more easily obtained. Existence of two functions side by side sometimes leads to recrimination if not under same control.

Disadvantages: The works manager being responsible for manufacture, ability to override chief inspector may result in bad production or bad production methods being concealed and quality will suffer.

(*d*) *Advantages:* Sales manager is in close contact with customer and therefore has ability to ascertain the type and quality of products required. (This is not a very common form of control.)

Disadvantages: Sales being usually a commercial or clerical function, little knowledge of design or manufacturing requirements and difficulties may be present, and an inability to realise these result in lack of ability to judge.

(*e*) Would usually occur where the chief inspector is a director or has connections with ownership. Is a very desirable condition.

Inspection Procedure will depend upon the type of inspection applied in the organisation.

Types of Inspection.—The chief types of inspection are as follows:

(1) Process inspection.
(2) Floor inspection.
(3) Sampling.
(4) Operation inspection.
(5) Cage.
(6) Quality control.
(7) Final inspection.
(8) Testing of completed product.
(9) Tool inspection.

Process Inspection is the most important of all types, and in reality comprises several of the others, viz. floor inspection, operation, and cage. The term is used to cover all the forms of inspection which deal with the work in process.

Organisation for Process Inspection.—The procedure to be used in process inspection is generally as follows:

(1) Setting of adjustable limit gauges, and issue of these, together with fixed gauges for the job.

(2) Checking of first pieces off to control correct setting of machine.

(3) Checking of work by (*a*) floor inspection, (*b*) operation inspection, and (*c*) cage inspection while work proceeds.

(4) Checking of batches or complete order when latter is fulfilled.

The setting of adjustable limit gauges should be a job that is always undertaken by the inspection department who will hold the necessary setting gauges (Johannsen slips, etc.) for these. The gauges when set should always be sealed and labelled. Checks should be made at intervals to cover the possibility of interference by unauthorised persons.

The issue of some form of chit covering the acceptance of the first pieces off or a signature on the job card to cover the same is essential. No job should be permitted to run until this cover is obtained. As the work proceeds, the type of inspection in use will be applied according as conditions require. When the work is complete or as suitable batches are ready, such as a day's run or a work-tray full of parts, these are passed to the inspection department for final check before passing to stores or part-finished stores for holding for next operation. At this stage the inspection chit and move card for the piece are dealt with by the inspector responsible and the clerical personnel, who then pass these to the production department.

Floor Inspection or Patrol Inspection consists in the constant patrol by suitably qualified inspectors from machine to machine to check the parts immediately produced by the machine. In this manner a large saving of scrap may be effected where the setting has deteriorated, the operator failed to produce correctly, or is unable to use gauges correctly. By this means a constant check is kept on production. Where adequate gauging facilities are provided, female inspectors are quite capable of this work, provided they are supported by a suitable senior staff to whom they can refer difficulties.

A variant of floor inspection is a shop centralised inspection at which the inspection of a conveniently arranged percentage can be made. This has been successfully applied in a casting machining department, where the operator takes several castings either near the end of a full worktray or near around each fifty machined to a nearby central inspection crib. A simple check that this instruction is carried out is that there shall appear on the back of the job ticket as many check stampings as there are fifties in the complete batch of work. This forms a fairly safe means of checking work in process, and by this arrangement never more than fifty in a batch can be defective. Whilst this quantity may seemingly be large, experience shows that this is not so when spread over a long period of working.

How Process Inspection aids Production.—An important aspect affecting the use of process inspection in whatever form is the consideration which should be given to the reasons which are the underlying causes of defective work. These are:

(1) Failure by operator to carry out instructions due (*a*) to unsatisfactory or insufficient training; (*b*) inability of operator to perform task.

(2) Defective jigs, fixtures, tools, etc.

(3) Bad setting.

(4) Wear on tools, which results in the setting becoming incorrect.

Training Operator.—This is an important preliminary to carrying out work, and much work is spoiled because it is not properly given. The inspection department performs an important task in drawing attention to this when work which is defective through this fault comes to its attention.

Unsuitable Operator.—This will also become apparent through the defective work which will be found by a suitable process inspection.

Defective Jigs, Fixtures, and Tools.—These are a ready means of causing scrap, either because they are dimensionally incorrect or because they allow of improper usage. One aim of good jig design is to provide foolproof jigs, etc., and where this has not been applied process inspection forms a means of drawing attention to it.

Bad Setting in the original may not be obvious from the first-off pieces as machine may soon become unset due to failure to tighten jigs, slides, tools, or due to improper sharpening of cutting tools.

Wear on Tools is most often due, apart from legitimate wear over a period, to poor machine or improper sharpening. The continued production of defective work will draw attention to this when process inspection is sufficiently applied to find bad work in small batches.

Operation Inspection is that which takes place when each batch has reached the end of the operation and before the batch is passed to the next operation, process, or machine. It is a good means of checking work without passing it to completion and the greater involved cost if incorrect. It should, however, be used in conjunction with either of the other forms of process inspection—floor or cage—if the minimum amount of work is to be defective.

Cage Inspection is a more recent form of inspection in which an attempt is made to keep inspection in step with production. In this type of inspection the machines are arranged round a fenced portion of the works which houses an inspection staff and equipped with the necessary benches and gauges (Fig. 4). The fence is provided with serving hatches adjacent to each machine, through which work is passed in convenient batches suitable for the inspector to handle. Those parts passing the gauges are retained within the cage, and the parts defective are passed back to the operator for scrapping or rectification. It is claimed for this type of inspection that:

(1) Scrap is reduced to a minimum.
(2) Quantities are more easily controlled.
(3) Movement of work is reduced.
(4) The flow of work is more even.
(5) Saving of labour is effected.

A positive reduction in scrap is certain because of the intimate close connection between production and inspection, preventing the making of an excessive number of parts before errors in the production are discovered. Because of this same close connection a better check than otherwise can be kept on the number made and allowance for scrap can be reduced. The close proximity of the inspection cage shortens the distance which the work has to travel, also resulting in a more even flow of work through the shops. Where possible, rectification is carried out by the operator as soon as convenient, this again resulting in more easy control of quantities. It is claimed that actual scrap was reduced to less than 50 per cent. of that made before the introduction of this type of inspection. Chasing is reduced to a minimum and holdups are less frequent.

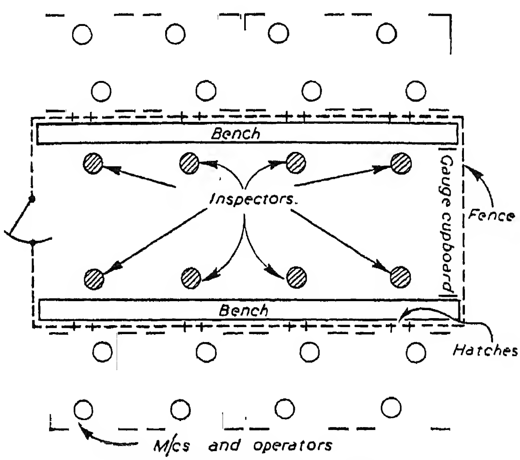


Fig. 4.—Diagram showing arrangement for cage inspection system.

100 per cent. Inspection.—The most effective form of inspection implies the checking of the parts, say, 100 per cent., and this may be often necessary where a fault in one major part may affect the operation of a completed product, or where the parts are known to be subject to difficulty in manufacturing and liable to errors. It is beneficial to institute 100 per cent. inspection where the parts are liable to the troubles stated.

Sampling.—A form of inspection in which the parts checked are less than

100 per cent. is known under the term "sampling." This system implies that by taking at random a small or large number of parts, a representation of the whole batch will be given. This, of course, cannot be true, but the system often finds use in practice with mostly satisfactory results. A good example of sampling is the drilling of metal ingots for analysis. The checking of the first piece off is a form of sampling in which it is assumed that whilst the machine remains as originally set, the pieces subsequently made will be correct. The necessity for following up the checking of subsequent parts is obvious. Experience is the only guide to what percentage inspection is necessary, and this requires a thorough knowledge of the standard of production available and the requirements of the product.

A development of sampling which is more thorough than is represented by the mere term sampling is that known as statistical sampling.

Statistical Sampling is the method of applying the laws of statistics to the inspection of products. A good example of this is the system used by the American organisation Bell Telephone Laboratories Inc., and known as double sampling. It is used on incoming goods for which records have been compiled of the general overall quality of the product as previously delivered. This estimate is called the Process Average Percentage Defective (p) for the given product from the subcontracting firm.

The procedure used is as follows:

Convenient lot sizes are taken, which should be as large as possible.

A first sample of n_1 is inspected.

If a number of defectives found in this First Sample

Does not exceed C_1 | Exceeds C_1 but not C_2 | Exceeds C_2

Inspect a second sample of n_2 pieces

If the number of defectives in $n_1 + n_2$

Does not exceed C_2 | Exceeds C_2

Accept the lot. | Reject the lot.

The values of n_1, n_2, C_1, and C_2 are estimated by:

(1) p, the process average percentage defective for the firm.

(2) Size of the incoming lot.

(3) Acceptable average quality for production, called by the originators the Average Outgoing Quality Limit (A.O.Q.L.).

(4) Lot tolerance (pt), which limits the chance of any individual bad lot being accepted.

Tables have been drawn up which connect all these values, of which Table I is an example for a lot tolerance defective of 3 per cent.

TABLE I (SHOWING VALUES
LOT TOLERANCE PER CENT. DE

Process Average Per Cent.	0–0·03						0·04–0·30						0·31–0·60				
Lot Size	Trial 1		Trial 2			AOQL Per Cent.	Trial 1		Trial 2			AOQL Per Cent.	Trial 1		Trial 2		
	n_1	C_1	n_2	n_1+n_2	C_2		n_1	C_1	n_2	n_1+n_2	C_2		n_1	C_1	n_2	n_1+n_2	C_2
1–40	All	0	—	—	—	0	All	0	—	—	—	0	All	0	—	—	—
41–55	40	0	—	—	—	0·18	40	0	—	—	—	0·18	40	0	—	—	—
56–100	55	0	—	—	—	0·30	55	0	—	—	—	0·30	55	0	—	—	—
101–150	70	0	30	100	1	0·37	70	0	30	100	1	0·37	70	0	30	100	1
151–200	75	0	40	115	1	0·45	75	0	40	105	1	0·45	75	0	40	115	1
201–300	75	0	40	115	1	0·50	75	0	40	105	1	0·50	75	0	40	115	1
301–400	80	0	45	125	1	0·52	80	0	45	125	1	0·52	80	0	85	165	2
401–500	85	0	50	135	1	0·53	85	0	50	135	1	0·53	85	0	90	175	2
501–600	85	0	50	135	1	0·54	85	0	50	135	1	0·54	85	0	95	180	2
601–800	90	0	50	140	1	0·55	90	0	95	185	2	0·64	90	0	135	225	3
801–1000	90	0	55	145	1	0·56	90	0	100	190	2	0·66	90	0	140	230	3
1001–2000	90	0	60	150	1	0·58	90	0	105	195	2	0·70	90	0	190	280	4
2001–3000	90	0	60	150	1	0 59	90	0	155	245	3	0·80	90	0	200	290	4
3001–4000	95	0	105	200	2	0·72	95	0	155	245	3	0·80	95	0	235	330	5
4001–5000	95	0	105	200	2	0·73	95	0	155	250	3	0·81	150	1	230	380	6
5001–7000	95	0	105	200	2	0·73	95	0	155	250	3	0·81	150	1	230	380	6
7001–10000	95	0	105	200	2	0·73	95	0	155	250	3	0·81	150	1	275	425	7
10001–20000	95	0	105	200	2	0·74	95	0	200	295	4	0·92	150	1	320	470	8

Application

Let sub-contractor's process average = 1·5 per cent.
Lot size . . . . . . = 2500
Then, from table :

$$n_1 = 290$$
$$C_1 = 4$$
$$n_2 = 470$$
$$n_1 + n_2 = 760$$
$$C_2 = 16$$
$$\text{A.O.Q.L.} = 1{\cdot}2 \text{ per cent.}$$

Thus, if first sampling of 290 parts has defectives not exceeding 4, then the lot will be accepted. If the defectives exceed 16, then they are all rejected. If, however, the defectives exceed 4 but not 16, then a second sampling is carried out of 290 + 470 = 760 parts. If the defectives again do not exceed 16, then the lot will be accepted, but will be rejected if exceeding 16.

This method ensures that the defectives reaching the stores or production line will not exceed 1·2 per cent.

The use of the table also ensures that if a lot is delivered having 3 per cent. or more defective (the Lot Tolerance), then the batch will be rejected 9 times out of 10.

The table could be used to indicate the necessity for 100 per cent. inspection if the C_2 figure were exceeded.

Quality Control is a method of controlling, at the point of production, the quality of the parts made and indicating the tendency of the manufacturing limits by the application of statistical methods and control charts.

Statistical Methods, by the application of mathematical theory to the

FOR DOUBLF SAMPLING)

FECTIVE = 3 PER CENT. (P_t).

	0·61–0·90						0·91–1·20						1·21–1·50					
AOQL Per Cent.	*Trial* 1		*Trial* 2			*AOQL Per Cent.*	*Trial* 1		*Trial* 2			*AOQL Per Cent.*	*Trial* 1		*Trial* 2			*AOQL Per Cent.*
	n_1	C_1	n_2	n_1+n_2	C_2		n_1	C_1	n_2	n_1+n_2	C_2		n_1	C_1	n_2	n_1+n_2	C_2	
0	All	0	—	—	—	0	All	0	—	—	—	0	All	0	—	—	—	0
0·18	40	0	—	—	—	0·18	40	0	—	—	—	0·18	40	0	—	—	—	0·18
0·30	55	0	—	—	—	0·30	55	0	—	—	—	0·30	55	0	—	—	—	0·30
0·37	70	0	30	100	1	0·37	70	0	30	100	1	0·37	70	0	30	100	1	0·37
0·45	75	0	40	115	1	0·45	75	0	65	140	2	0·47	75	0	65	140	2	0·47
0·50	75	0	80	155	2	0·54	75	0	80	155	2	0·54	75	0	80	155	2	0·54
0·57	80	0	85	165	2	0·57	80	0	120	200	3	0·62	80	0	120	200	3	0·62
0·60	85	0	125	210	3	0·64	85	0	125	210	3	0·64	85	0	160	245	4	0·69
0·62	85	0	130	215	3	0·67	85	0	170	255	4	0·72	135	1	185	320	6	0·76
0·70	90	0	170	260	4	0·74	140	1	195	335	6	0·79	140	1	210	350	7	0·81
0·72	90	0	180	270	4	0·77	145	1	235	380	7	0·85	145	1	270	415	8	0·86
0·84	150	1	210	360	6	0·90	150	1	325	475	9	1·00	195	2	350	545	11	1·10
0·86	150	1	300	450	8	1·00	200	2	365	565	11	1·10	290	4	470	760	16	1·20
0·92	150	1	350	500	9	1·10	245	3	405	650	13	1·20	330	5	545	875	19	1·20
0·98	200	2	340	540	10	1·20	250	3	445	695	14	1·20	380	6	620	1000	22	1·30
1·00	200	2	385	585	11	1·20	250	3	530	780	16	1·30	380	6	700	1080	24	1·40
1·00	200	2	425	625	12	1·20	250	3	575	825	17	1·30	425	7	785	1210	27	1·50
1·10	200	2	475	675	13	1·30	295	4	655	950	20	1·40	470	8	900	1370	31	1·60

measurement of variability of manufacture, give rules which guide the action necessary to reduce this variability. The choice of practical and economical batch sizes is indicated by these methods so that the quality of the bulk quantities can be inferred by the tests so made. By the use of this method information is made available which will enable the producer to correct faults in production as they occur, and avoid the waste which results from uncontrolled methods wherein the inability to cure the faults as they arise is inherent. Thus the purposes of the method are used to ensure the following:

(1) Regularity on consistency of performance.
(2) Uniformity of product.
(3) A mean level of production.

It is to be noted that this method does not and cannot aim at indicating the causes of variability or at reducing it, but provides a means of measuring it and guiding the producer in taking the action necessary to secure its reduction.

The statistical methods provide the necessary data to ensure a correct attitude to the variations found in testing samples, and replace the chaotic application of new methods or drastic action which often occurs when trouble is met with in finding bad work.

Where 100 per cent. inspection has been considered necessary in the past, the use of the statistical methods may lead to a reduction in the amount of inspection by using the accurate information that is usually obtained from samples.

Thus, the planning of inspection methods can lead to a reduction in manufacturing costs.

Enumerated below are the six points which are the purposes of the method:

(1) To aid in distinguishing between real and apparent variations.

(2) To provide a warning of a new source of variation or an increase in the variation where this is known to exist.

(3) To determine the size of the sample relative to the reliability it is possible to place on the inspection.

(4) To determine whether the quality shall be based upon the average test value or their range, by the proportion of the variations in the test values or by some other statistical measurement.

(5) To trace the source of the variability, identify its causes, and determine the relative sizes of the variations due to different sources.

(6) To judge between different methods possible for reducing the variations when a cause has been identified.

For the application of statistical methods certain conditions are absolutely essential and as a minimum; these are:

(1) Manufacture is controlled so that the product does not change in respect of the magnitude or quality on which the method is applied.

(2) From previous experience a commercially attainable standard of quality is assumed.

(3) Statistical theory is used to set the limits within which the inspection results for a representative sample should fall on a convenient number of occasions if the sampling is repeated many times, under the conditions of controlled manufacture. Guidance is also given by this means as to the size of the sample and the convenient number of occasions on which the sampling shall be made. The number of the former and size of the latter must, of course, be based on other considerations, such as cost of the inspection and the permissible magnitude of the variation of the quality, having regard to the total cost and ultimate quality of the product.

Experience shows that the convenient proportions as mentioned above are 19 times out of 20 and 499 times out of 500.

Use of the above conditions allows one to assume that if the results obtained in the inspection fall within the limits given, as (3), then the samples are within the control limits and no further sampling is required. If the results fall outside these limits, then further sampling is necessary.

Direct Aid to Inspection by Sampling.—It will thus be seen from what has been stated above that the statistical method is a direct aid to inspection by sampling once the allowable deviation from given standards and the proportion of defective work are known.

How Aid to Inspection is Obtained.—The use of the laws of probability for the sampling of specimens from a given bulk of work is one of the practical uses to which the methods of quality control are put. The theory used for the method provides data as to the frequency with which defective parts will be found when sampling is carried out. It will be easily understood that when sampling parts in which defectives are known to exist, if the number expected is one defective per sample then many of the samples will contain no defectives whilst others contain up to six defectives.

The curve given in Fig. 5 provides a means of ascertaining where the samples are showing signs of deterioration. The figure gives two ranges of curves, viz. one pair for the 19/20 limits and one pair for the 499/500. That is to say, that one pair of curves gives the number of defectives which will be found in the sample 19 times out of 20 and 499 out of 500, if we carry the sampling to these number of times. The curves are used as follows:

Suppose that we know that the number of defectives expected is 7, then from the curves we find that the 19/20 limit is 2 and 13, and for the 499/500 limit is nil and 17. Using the higher figure in each case, i.e. 13 and 17, we are given an indication that should any sample contain more than these defectives, then the production is unstable and the expected number is exceeded. However, where this occurs only infrequently or on a sole occasion, further sampling should be undertaken and the two samples treated as one, wherein a double number of defectives expected should be used and new control limits used.

A further series of curves (Fig. 6) is useful as a means of showing the probability that a given number of defectives will occur in a sample which is expected to contain that number of defectives relative to the bulk. The curves are used as follows:

The number of defectives expected, $\bar{m}$, is read along the abscissa, and the

curves which cut the vertical lines for $\overline{m}$ give the number of defectives, m or more, which will be found in a sample, both being proportional to the bulk. The horizontal values are the probability that m or more samples will be found when $\overline{m}$ samples are expected.

Thus, suppose the average number of defectives expected to be 1 ($\overline{m} = 1$), then the probability that 4 or more defectives will be found in the sample = 0·02, i.e. where the curve for $m = 4$ cuts the vertical line $\overline{m} = 1$ reads 0·02, therefore 4 or more defectives will be found in 1 in 50 samples when the average number of defectives is expected to be 1. Also, that 2 or more defectives will be found has the probability value = 0·25 and will thus be found in 1 in 4 samples.

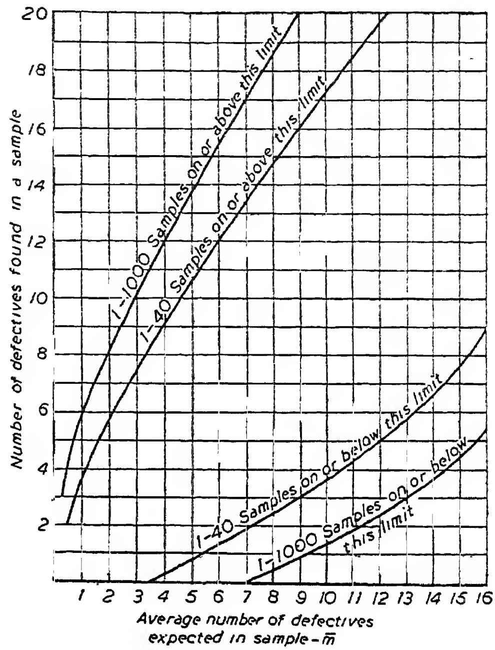


Fig. 5.—Graph showing probability of frequency of defective parts.

To sum up, we read Fig. 6 thus:

(*a*) Along horizontal ordinate the number of defectives per sample proportional to the bulk.

(*b*) On curved lines number of defectives which will be found in the sample 1 or more, 2 or more, etc.

(*c*) Ratio on vertical ordinate, viz.

$$\frac{\text{number of times 1 or more, 2 or more, etc.}}{\text{number of samples}}$$

Use of Fig. 6 in Checking Samples.—We make use of the data provided by Fig. 6 for checking possible deterioration of product by repeated sampling, and can use it to show the extent to which a change in the proportion of defectives would have to occur before a warning of a change in quality need be acted upon.

From Fig. 6 we compile the values given in Table II, which shows the number of defectives in the sample will change with an increase in the number of defectives expected, and will thus give a warning that a change in the quality is occurring. Referring to the table, it will be seen that if the number of defectives increases so that 2 defectives on the average will be expected in a sample, 3 or more defectives will be found once in 3 samples instead of once in 13 samples when the product contained 1 defective in the sample on the average. Similarly 4 or more defectives will occur once in 7 samples instead of once in 50 samples when the product contained 1 defective per sample on the average. Thus the occurrence of 3 or 4 defectives in frequencies given will serve as a warning that the production may be deteriorating, and will indicate the point at which an investigation into the method of production is necessary.

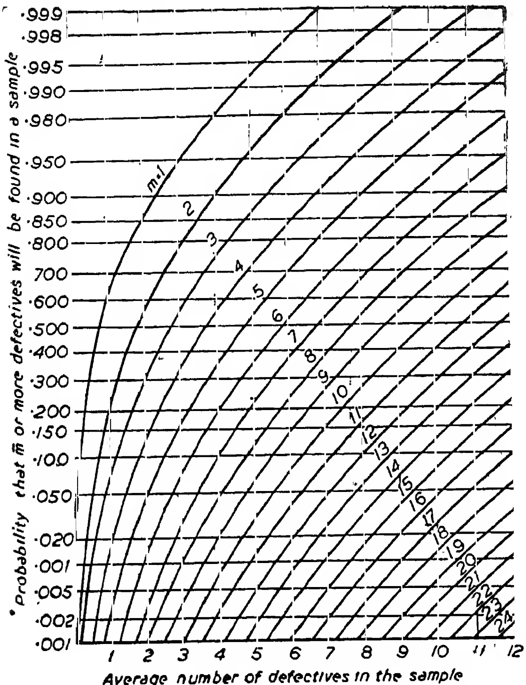


Fig. 6.—Graph showing probability of frequency with which a given number of defectives will occur in a sample.

Dot Diagrams.—An important graphical aid to the statistical method is the dot diagram, of which Fig. 7 is an example. Vertically we read the number of defectives found in the sample and horizontally the sequence of the samples taken. The control limits are represented by dotted lines. The example given would be that for an average of 1 defective expected per sample, because the dotted lines are placed at 3·7 and 5·5 which, by reference to Fig. 5, will be seen as being the upper limits for the number expected. As each sampling is made a dot is placed on the diagram for the number of defectives found. This serves to indicate the variations in the number defective per sample; place this number against the lines given for the limits. As the dots are placed on the diagram a watch is kept for the numbers defective relative to the number of samples made, and by checking with Table II it can be seen whether a tendency towards a change in quality is likely. On the one hand, the occurrence of a dot near to the inner limit would tend to show that a change was taking place relative to the number of defectives in the bulk. This occurs with samples 14 and 17, and at this latter point a further check should be made to verify whether such were the case. By compounding the last eight results the total number of defectives could be found, namely 13 instead of 8, which should be expected. By reference to Fig. 5 we find that for 8 defectives expected per sample the inner limit is 15 defectives, and it is therefore doubtful if a change has taken place. On the other hand, the occurrence of 3 defectives twice in the last 3 samples, viz. samples 21 and 23, and the occurrence of 3 or more defectives 4 times in the last 14 samples, seems to indicate a change, and by comparing the number of occurrences with Table II where under the column for 1 expected defective the occurrences are given as 1 in 13, this frequency of 3 defectives suggests that a change has occurred. By further compounding of the last, say, 10 samples where 16 defectives were found instead of the expected 10, we test again by reference to Fig. 5, where we find the inner limit to be 17, so that a change is doubtful.

Use of the Tables in Production.—A simple application of tables similar (but modified to suit production purposes) to Table II would be where these were used whilst production was proceeding. In this case the use of GO and NO GO

gauges would be expected and the assumption made that production would be preferred so that the sizes were in the mean of the total tolerance. A logical assumption from this would be that half the defective parts would fail the " Go " gauge and half would fail the " No Go " gauge. For simplicity in showing the use of the table we have chosen such a case, but where production was preferred to keep either nearer to the " Go " gauge or the " No Go " gauge, the ratio of those failing the gauge would be pro rata, and two tables would be necessary. The dot diagrams would be used to record the defectives as above, one for those failing the " Go " gauge and one for the " No Go " gauge. In a similar manner as in Table II we construct Table III. However, the average number of expected defectives now becomes 0·5, 1, and 1·5, instead of 1, 2, and 3, as in Table II.

Where changes due to tool wear are likely, some thought is necessary as to the direction in which they will take place, i.e. in cutting externally, as in turning, the wear will tend to make parts that are large, and allowance must be made for this by setting the tool to produce parts that are towards the low limit, and few defectives will be likely on the one-dot diagram. As tool wear increases the number of dots on this latter dot diagram will tend to rise, and thus indicate a warning that resetting of the tool may be necessary.

In the case of Table III if the number of defectives does not exceed 2 once in 10 samples, then it will be seen that a change in the product is unlikely. If 3 or more defectives are found, then a change is indicated, as this should occur

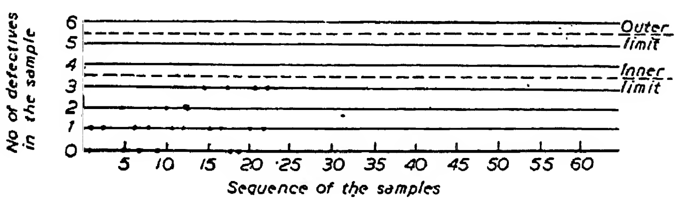


Fig. 7.—The dot diagram.

once only in 100 samples. Thus, supposing the article to change so that 2 fail to pass one or other gauge, then the chance of 3 or more articles failing either gauge shows an increase sufficient to give warning of the change.

In a case in which the number of defectives per sample changed for 2 to 3 or more on one diagram, to 2 to 3 or more on the other, such erratic behaviour would be unlikely to be that due to tool wear, and other causes would have to be ascertained. The diagrams should be used to make this investigation and detect whether the causes were due to—

(*a*) Raw material.
(*b*) Different machines.
(*c*) Different operators.

Terms used in Quality Control.—Before proceeding further it is essential that a number of terms frequently used hereinafter shall be defined. These terms are the ones commonly used in Quality Control and have been accepted as standard. The algebraic forms which cover these derivations are also given, as it is believed essential to grasp these before further information is presented.

Sample.—A sample is a portion of material or group of components taken from a given bulk, which is used to give data as to the quality of the bulk.

Individual.—An individual is any one of the components in a sample.

Observation or Observed Value is the value of some quality characteristic which has been measured or observed for an individual.

Defective.—Any individual in a sample or a component in a bulk which is not desirable from the control view-point is a " defective." A defective is not necessarily a useless component.

TABLE II

Number of Defectives in Sample	*Average Number of Defectives expected in the Sample (proportional to the defectives in the bulk)*		
	1	2	3
	Approximate proportion of occurrences in repeated sampling		
0	7 in 20	3 in 20	1 in 20
1 or more	13 in 20	17 in 20	19 in 20
2 or more	5 in 20	12 in 20	16 in 20
3 or more	1 in 13	1 in 3	2 in 3
4 or more	1 in 15	1 in 7	1 in 3
5 or more	1 in 250	1 in 20	1 in 5
6 or more	1 in 1500	1 in 60	1 in 12

TABLE III

Number of Defectives in Sample	*Average Number of Defectives expected in the Sample (proportional to the defectives in the bulk)*		
	0·5	1·0	1·5
	Approximate proportion of occurrences in repeated sampling		
0	12 in 20	7 in 20	4 in 20
1 or more	8 in 20.	13 in 20	16 in 20
2 or more	2 in 20	5 in 20	9 in 20
3 or more	1 in 100	1 in 13	1 in 5
4 or more	1 in 600	1 in 50	1 in 15

Parameter is a representative measure of a quality characteristic of which some of the following terms are examples (sample mean, sample range, grand mean, etc.).

Sample Mean is the average or mean of all the observed values for the individuals in the sample. Symbol $\bar{x}$.

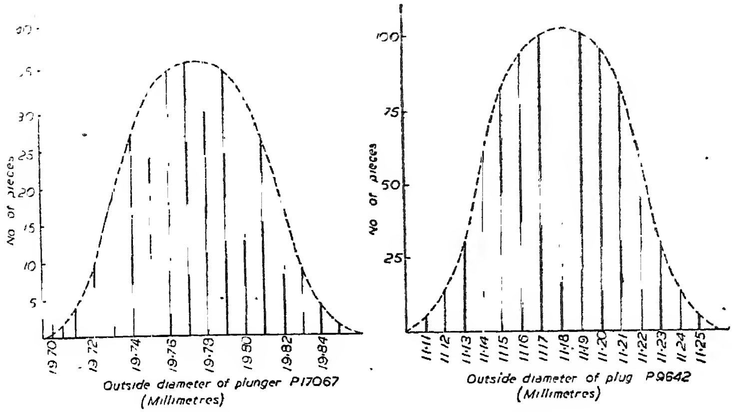
$$\bar{x} = \frac{x_1 + x_2 + x_3 \ldots x_n}{n}.$$

Grand Mean or Bulk Average is the mean or average of a number of sample means or the average of the averages. Symbol $\overline{X}$.

$$\overline{X} = \frac{\bar{x}_1 + \bar{x}_2 + \bar{x}_3 \ldots \bar{x}_n}{n}.$$

Sample Range is the difference between the smallest individual in the sample and the largest. Symbol w.

$$w = x_n - x_1.$$



Figs. 8 and 9.—Curves of results of sampling.

Average Range is the average of the sample range of a number of samples. Symbol $\bar{w}$.

$$\bar{w} = \frac{(x_n - x_1) + (x_n - x_2) + (x_n - x_3), \text{ etc.}}{n}.$$

Median.—Either the value which lies between the two observations which have the middle values when an even number of observations are stated in a progressive series, or the middle value when the series has an odd number. Thus, if there are odd numbers :

$$n = 2a + 1, \text{ the median value will be } x_{a+1}.$$

If n is an even number the median value will be :

$$\frac{x_a + x_{a+1}}{2}.$$

Midpoint is the value half-way between those of the minimum and maximum observations, i.e. :

$$\text{Midpoint} = \frac{x_1 + x_n}{2}.$$

Deviation is the difference between any one observation and the average of the observations. Symbol σ.

The deviations for difference observations are :

$$(x_1 - \bar{x}), (x_2 - \bar{x}), (x_3 - \bar{x}) \ldots (x_n - \bar{x}), \text{ etc.}$$

Standard Deviation is the square root of the average of the squares of all the deviations. Symbol S.

$$S = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 \ldots (x_n - \bar{x})^2}{n}}.$$

Mean Deviation is the average of all the deviations.

$$\text{Mean deviation} = \frac{(x_1 - \bar{x}) + (x_2 - \bar{x}) + (x_3 - \bar{x}) \ldots (x_n - \bar{x})}{n}.$$

NOTE.—Where the deviations have a negative value (i.e. when the sample has a value greater than that of the sample mean) they must be converted to a positive value.

Dot Diagram.—A diagram in which the observations are plotted by means of dots in their position on a scale relative to their sequence of observation and value.

Frequency.—The number of observations which have a value between two specified limits.

Gaussian Distribution.—Sufficient indication has been given above to show that the sampling of work by statistical methods is a practical proposition, and we pass now on to the methods used for mathematical aspects of the subject. Table IV gives examples taken from practice of the allowable variability of dimensions and qualities of three products after testing.

The common condition applying to all these parts is that they have been manufactured under a system of *controlled* or *stable* production. That is to say, attention has been paid to correcting faults in quality or dimension as they arise, and the variability is due to such factors as are allowable having regard to limitations imposed by cost and difficulties of manufacture.

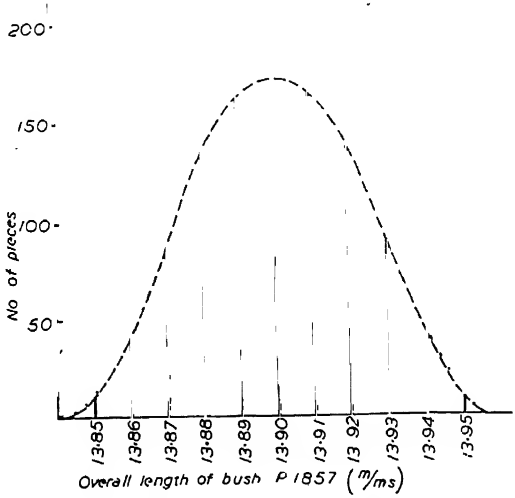


Fig. 10.—Curve of result of sampling.

In each case the results have been plotted (Figs. 8–10) so that the range of variability has been divided into a number of parts (plotted horizontally), and the number of parts falling in each is plotted vertically. It will be noted that each figure describes a similar curve, giving a distribution which is called Normal or Gaussian.

The Normal or Gaussian distribution is defined as " that which will result when a large number of independent causes operate by chance to introduce deviations from an objective."

A further useful point is that this distribution tends to cluster about a central value, the number of parts becoming fewer as they increase in difference from this central value. From the data derived from the samples and their deviation, two classes of measure (called parameters) are noted, viz. :

(*a*) Values denoting order of magnitude.
(*b*) Values denoting spread, dispersion, or deviation.

In class (*a*) we have the average, median, midpoint, etc., each of which we define as given on pages 1016–17.

TABLE IV

Part No.	Part	Dimension	Size mm. H	Size mm. L	$\overline{X}$ Average of Samples	σ Standard Deviation	Percentage of Observations Outside Average $\overline{X}-\sigma$	$\overline{X}+\sigma$	$\overline{X}-2\sigma$	$\overline{X}+2\sigma$	$\overline{X}-3\sigma$	$\overline{X}+3\sigma$
P17067	Plunger	Outside diam.	19·70	19·85	19·78	0·046	12·5	15·5	2·1	1·9	0·12	0·16
							28		4·0		0·28	
P9642	Plug	Outside diam.	11·11	11·25	11·18	0·043	14·2	15·6	1·8	1·7	0·13	0·15
							29·8		3·5		0·28	
P1857	Bush	Overall length	13·85	13·95	13·91	0·034	16·9	13·7	1·9	1·8	0·14	0·10
							30·6		3·7		0·24	

Note.—The three parts P17067, P9642, P1857 have been subjected to test by quality control in respect of one of each of their most important dimensions, viz. :

P17067 Outside diameter .. .. $19{\cdot}77 \begin{smallmatrix} +\ 0{\cdot}08 \text{ mm.} \\ -\ 0{\cdot}07 \text{ mm.} \end{smallmatrix}$

P9642 Outside diameter .. .. 11·18 ± 0·07 mm.
P1857 Over-all length .. .. 13·90 ± 0·05 mm.

In each case after sampling the bulk average $\overline{X}$ has been found by use of the formula :

$$\overline{X} = \frac{\bar{x}_1 + \bar{x}_2 + \bar{x}_3 \,\ldots\ldots\ldots + \bar{x}_n}{n}$$

The expression $\bar{x}$ is for the sample average, which has been found for each sample taken. The size of the samples was as follows :

P17067 5 individuals. P9642 8 individuals. P1857 3 individuals.

In the case of P1857, this part had been frequently made before, and the knowledge gained in making the part, together with the experience gained in using quality control, had enabled the observer to cut the individuals to the given small quantity. In this connection it can be stated that the continued use of quality control will enable one to quickly interpret the data derived from its use, and the size of the samples and their relation to the bulk can be reduced to a minimum. One has constantly to be on the watch for the human factor, however, and in this respect some judgment needs to be used.

A good test for reliability is the relation of the bulk average to the drawing mean dimension.

It must be borne in mind that we are checking the actual samples and not an ideal number.

Table V

Gaussian Frequency Distribution

(giving proportions of observations for values of t = multiple of standard deviation)

	Proportion of Observations Below $X - t\sigma$ *or Above* $X + t\sigma$	*Proportion of Observations within the Limits* $X - t\sigma$ $X + t\sigma$		*Proportion of Observations Below* $X - t\sigma$ *or Above* $X + t\sigma$	*Proportion of Observations within the Limits* $X - t\sigma$ $X + t\sigma$
0·0	0·500	0·000	2·0	0·023	0·954
0·1	0·460	0·079	2·1	0·018	0·964
0·2	0·421	0·158	2·2	0·014	0·972
0·3	0·382	0·236	2·3	0·011	0·979
0·4	0·345	0·310	2·4	0·008	0·984
0·5	0·308	0·383	2·5	0·006	0·988
0·6	0·274	0·451	2·6	0·005	0·991
0·7	0·242	0·561	2·7	0·0035	0·993
0·8	0·212	0·516	2·8	0·0026	0·995
0·9	0·184	0·632	2·9	0·0019	0·996
1·0	0·159	0·683	3·0	0·0013	0·997
1·1	0·136	0·729	3·1	0·0010	0·9981
1·2	0·115	0·770	3·2	0·0007	0·9986
1·3	0·097	0·806	3·3	0·0005	0·99903
1·4	0·081	0·838	3·4	0·00034	0·99933
1·5	0·067	0·866	3·5	0·00023	0·99953
1·6	0·055	0·890	3·6	0 00016	0·99968
1·7	0·045	0·911	3·7	0·00011	0·99978
1·8	0·036	0·928	3·8	0·00007	0·99986
1·9	0·029	0·943	3·9	0·00005	0·99990

Class (*b*) parameters include such as range, standard deviation, coefficient of variation, mean derivation, etc.; also defined on pages 1016–17.

It is an essential part of Quality Control that erratic observations obviously not related to the complete range are ignored, so that dependence is made more on average values. Thus in class (*a*) we most commonly use the average values such as the bulk average ($\bar{X}$) and the sample average ($\bar{x}$). The formulæ for finding these are given with their definitions on pages 1016–17.

In class (*b*) the most important parameters are standard deviation (σ) and the sample range (w). The definitions and formulæ for these are given on pages 1016–17. The latter, however, has the more practical use, as it is more easily ascertained.

Table IV gives the average and standard deviation for each example.

Provided that the distribution of the sampled components follows the Gaussian distribution as defined above, it has the property of being defined by the value of the average and standard deviation. Tables for the Gaussian distribution have been calculated which give the area of the curve lying outside the various deviations from the average value expressed as multiples of the standard deviation. By the use of these tables (Table V), the expected proportion of individuals within a given range of the scale of measurement can be calculated if the average value and the standard deviation are known.

Further columns in Table IV give the values:

$$\bar{X} \pm \sigma,\ \bar{X} \pm 2\sigma,\ \text{and}\ \bar{X} \pm 3\sigma.$$

These are useful means of checking when used for ascertaining the percentage of observations outside these limits. The use of these values is to ascertain

whether the sampling follows the Gaussian distribution. Derived from the tables we find the following values :

Observation having Value	*Percentage of Whole*
Less than $\overline{X} - \sigma$ or greater than $\overline{X} + \sigma$	15·9
Less than $\overline{X} - 2\sigma$ or greater than $\overline{X} + 2\sigma$ . . .	2·3
Less than $\overline{X} - 3\sigma$ or greater than $\overline{X} + 3\sigma$ . . .	0·1

From a chart of such values a curve can be constructed such as Fig. 11, which is that for the Gaussian distribution.

As a simple means of identifying the dot diagram with the Gaussian distribution refer to Fig. 12, which shows the connection between the number of parts falling within each value and their distribution.

Value of Gaussian Distribution.—Of academic and practical interest is the fact that the Gaussian distribution is proof that the manufacture giving such test results is stable and under control.

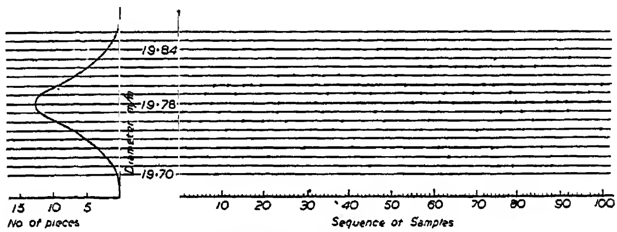


Fig. 11.—Gaussian distribution dot diagram.

It may happen that the distribution will deviate from the true form, and will be displaced to form what is termed a " skew " distribution, as shown in Fig. 13. However, experience shows that sampling made from the bulk having this " skew " distribution will tend to become more truly Gaussian if the numbers in the samples are increased. Figs. 14–15 show the results obtained from such further samplings, and it can be definitely stated that, where doubt occurs through lack of knowledge, use can be safely made of samples containing 4–10 articles.

Estimation of Variation of Average, Standard Deviation, etc.—It is obvious, as previously remarked, that when determining the parameters required for the practical application of Quality Control, differences will be found because of the differences possible in the samples. Allowance must, therefore, be made for these differences in the same way that it was made when sampling in the case where one defective was expected and 0, 2, 3, etc., were found (see pages 1014–15 and Table II).

Variation of Average ($\bar{x}$).—The laws governing the means (average) of a large number of samples of a given number n individuals taken at random from a normal population are well known.

The standard deviation of the average values of samples containing n individuals is given by the formula :

$$S = \frac{\sigma}{\sqrt{n}}$$

where σ = the standard deviation of the individual results for the bulk.

Thus, standard deviations for samples containing 5 and 8 individuals are $\frac{1}{\sqrt{5}}$ and $\frac{1}{\sqrt{8}}$ of the standard deviations for the individual samples. The greater the number of samples taken, the more nearly will the average value of a number of samples approximate to the bulk average. From the assumption of a control production and hence the approximation to a Gaussian distribution, the standard deviations can be used to calculate the control limits for sample averages $\left(\frac{\sigma}{\sqrt{n}}\right)$. The control limits are those referred to for the 19/20 and 499/500 limits. These are expressed as follows :

Inner limits : $\overline{X} - A_{0\cdot025} \times \sigma \quad \overline{X}\ A_{0\cdot025} \times \sigma$ for 19/20.

Outer limits : $\overline{X} - A_{0\cdot001} \times \sigma \quad \overline{X}\ A_{0\cdot001} \times \sigma$ for 499/500.

Thus, from a table (Table VI) giving the factors for $A_{0\cdot025}$ and $A_{0\cdot001}$ we can calculate the control limits as expressed by the following rule :

To obtain the control limits for the sample average multiply the standard deviation (σ) by the factor of $A_{0\cdot025}$ and $A_{0\cdot001}$ and add to or subtract from the average value $\overline{X}$.

The above rule can also be used to calculate the control limits for the average range of small samples $\bar{\omega}$ by substituting the former value for that of σ using instead the factors $A^1_{0\cdot025}$ and $A^1_{0\cdot001}$ in place of those of $A_{0\cdot025}$ and $A_{0\cdot001}$ (Table VI).

The relationship between $A_{0\cdot025}$ and $A^1_{0\cdot025}$ and $A_{0\cdot001}$ and $A^1_{0\cdot001}$ is expressed as follows :

$$\left.\begin{aligned} A^1_{0\cdot025} &= A_{0\cdot025}/d_n \\ A^1_{0\cdot001} &= A_{0\cdot001}/d_n \end{aligned}\right\} \text{using the values } d_n \text{ from Table IX.}$$

These factors should be used only when it is not necessary to calculate S for the samples and when sufficient data are available for making an accurate estimate of the standard deviation σ from the range $\bar{\omega}$. The number of individuals in the sample when using these factors should not exceed 12, as accuracy beyond this number is very unlikely.

Control Charts.—From the data given above we are able to construct charts against which test results can be checked by plotting the sizes of samples as they are taken from manufacture or bulk supplies. The chart so constructed is known as a "control chart," and is a ready means of indicating the variations which occur in either the manufacture as it proceeds or those found in components submitted for acceptance in a bulk supply. A clear understanding of the possibilities of the control chart is important for the purpose of applying Quality Control in practice, and to this end we give herewith a series of those connected with each of the important parameters.

It is to be observed that in each control chart are drawn the control limits of the parameter concerned,

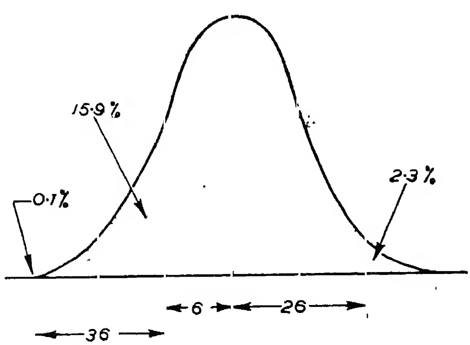


Fig. 12—Curve showing the connection between number of parts falling within each value and their distribution.

and it is from this fact that the chart is so named. The control limits are indicative of the limits to which the samples can vary.

Control Chart for Average $\bar{x}$ or $\bar{X}$.—Referring to Table IV, we give for each example the following data :

(*a*) Average of samples : $\bar{X}$.
(*b*) Standard deviation : σ.

Using example P9642 (Fig. 9 and Table IV), these values are :

$$\bar{X} = 11{\cdot}18 \text{ mins.}$$
$$\sigma = 0{\cdot}043.$$

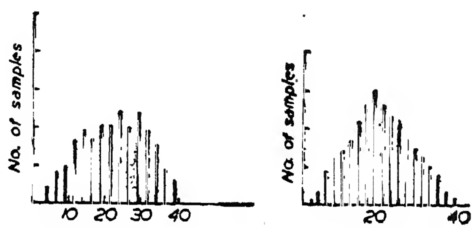
Assuming 5 individuals per sample, referring to Table VI, we find :

Inner limits : $\bar{X} \pm A_{0\cdot025} \times \sigma$
$= 11{\cdot}18 \pm 0{\cdot}876 \times 0{\cdot}043 = 11{\cdot}18 \pm 0{\cdot}038 = 11{\cdot}218$ and $11{\cdot}142$.

Outer limits : $X \pm A_{0\cdot001} \times \sigma$
$= 11{\cdot}18 \pm 1.382 \times 0{\cdot}043 = 11{\cdot}18 \pm 0{\cdot}059 = 11{\cdot}239$ and $11{\cdot}121$.

We construct a chart as Fig. 16 and show thereon the average 11·18 plotted vertically and indicated with a full line, the inner and outer limits at 11·218

Fig. 13.—Skew distribution.



Figs. 14 and 15.—Results obtained from further samplings.

and 11·142 ; 11·239 and 11·121 shown in dotted and chain-dotted lines, and the low and high limits, 11·11 and 11·25, respectively, given on the drawing.

Against these ordinates are plotted the means of the samples as found and as identified by the numbers given horizontally. Repeated sampling serves to indicate where a change in production conditions could be suspected, as at samples numbers 32 and 41.

Variation of Standard Deviation.—The calculation of the standard deviation of the samples (S) and the average range (ω) have already been shown. The distribution of the standard deviation of samples (S), which is approximately Gaussian, is known, and the calculation of its inner and outer control limits can thus be made.

The limits are :

Inner limits : $B_{0\cdot025} \times \sigma \quad B_{0\cdot975} \times \sigma$.

Outer limits : $B_{0\cdot001} \times \sigma \quad B_{0\cdot975} \times \sigma$.

The two new limits mean that 1 in 1000 values of σ are expected below $B_{0\cdot001}$ and 999 in 1000 values below $B_{0\cdot999}$. The factors for B are given in Table VII, which also gives a new value b_n. This latter is used to find the average value of $S = \bar{S} = b_n \times \sigma$.

Control Chart for Standard Deviation (S).—Using values as before, we are able to construct a control chart for the standard deviation, using the value $\sigma = 0{\cdot}043$ and number of individuals per sample = 5.

Construct a chart similar to Fig. 7, and show thereon the average 11·18 plotted vertically with a full line across the chart, the inner and outer limits at 11·218 and 11·142 ; 11·239 and 11·121 shown in dotted and chain-dotted lines, and the high and low limits, 11·11 and 11·25 respectively, given on the drawing, in heavy lines.

Against these ordinates are plotted the means of the samples as found and as given by their sequence in sampling horizontally.

Thus,

Inner limits : $B_{0 \cdot 025} \times \sigma = 0 \cdot 311 \times 0 \cdot 043 = 0 \cdot 0133.$
$B_{0 \cdot 975} \times \sigma = 1 \cdot 493 \times 0 \cdot 043 = 0 \cdot 0642.$

Outer limits : $B_{0 \cdot 001} \times \sigma = 0 \cdot 135 \times 0 \cdot 043 = 0 \cdot 0058.$
$B_{0 \cdot 999} \times \bar{\sigma} = 1 \cdot 922 \times 0 \cdot 043 = 0 \cdot 0826.$

Average value $\overline{S} = b_n \times \sigma = 0 \cdot 841 \times 0 \cdot 043 = 0 \cdot 0362.$

Variation of the Coefficient of Variation.—In some cases importance can often be attached to the value $\frac{\text{standard deviation}}{\text{average}} = \frac{\sigma}{\overline{\overline{X}}}$ known as the coefficient of variation, represented by the symbol v. The laws governing the distribution of v for a distribution which is approximately Gaussian are known, and from the factors so ascertained control charts for the limits can be calculated.

The limits are expressed as follows :

Inner limits : at $B_{0 \cdot 025} \times \frac{\sigma}{\overline{\overline{X}}}$ and $B_{0 \cdot 975} \times \frac{\sigma}{\overline{\overline{X}}}$.

Outer limits : at $B_{0 \cdot 001} \times \frac{\sigma}{\overline{\overline{X}}}$ and $B_{0 \cdot 999} \times \frac{\sigma}{\overline{\overline{X}}}$.

The average value of $v = \bar{v} = b_n \times \frac{\sigma}{\overline{\overline{X}}}$.

The factors for B and b_n are given in Table VII.

Little error occurs when the value of v is 20 per cent. or less when the samples contain 5 or more individuals.

For samples containing 5 to 30 individuals when the coefficient of variation is over 20 per cent., the following formula is to be used:

$$1 : \sqrt{C\left(1 + \frac{\overline{\overline{X}}^2}{\sigma^2}\right) - 1}.$$

Values of C are given in Table VII.

The average value of $v = \bar{v}$ is found by substituting C_n, given in Table VIII for C above.

Samples containing less than 5 individuals should not be used.

Control Chart for Coefficient of Variation.—As before, we are able to construct a control chart for the coefficient of variation, using the values :

$$\left.\begin{aligned}\overline{\overline{X}} &= 11 \cdot 18 \\ &= 0 \cdot 043\end{aligned}\right\} \therefore \text{ coefficient of variation} = \frac{0 \cdot 043}{11 \cdot 18}.$$

Assuming 5 individuals per sample :

Inner limits : $B_{0 \cdot 025} \times \frac{\sigma}{\overline{\overline{X}}} = 0 \cdot 311 \times \frac{0 \cdot 043}{11 \cdot 18} \times 100 = 0 \cdot 118$ per cent.

Inner limits : $B_{0 \cdot 975} \times \frac{\sigma}{\overline{\overline{X}}} = 1 \cdot 493 \times \frac{0 \cdot 043}{11 \cdot 18} \times 100 = 0 \cdot 574$ per cent.

Outer limits : $B_{0 \cdot 001} \times \frac{\sigma}{\overline{\overline{X}}} = 0 \cdot 135 \times \frac{0 \cdot 043}{11 \cdot 18} \times 100 = 0 \cdot 0518$ per cent.

Outer limits : $B_{0 \cdot 999} \times \frac{\sigma}{\overline{\overline{X}}} = 1 \cdot 922 \times \frac{0 \cdot 043}{11 \cdot 18} \times 100 = 0 \cdot 738$ per cent.

Average value $\bar{v} = b_n \times \frac{\sigma}{\overline{\overline{X}}} = 0 \cdot 841 \times \frac{0 \cdot 043}{11 \cdot 18} \times 100 = 0 \cdot 323$ per cent.

Variation of Range (ω).—The calculation of the range (ω) is very easily obtained from sample data, and for this reason is a convenient parameter to use. To ensure that accurate results are used, however, the number of individuals in the sample should be from 4 to 10, and in any case should not exceed 12. Also the distribution must be Gaussian.

TABLE VI

CONTROL LIMITS FOR AVERAGE ($\bar{x}$)

Number in Sample n	For Inner Limits $A_{0\cdot025}$	For Outer Limits $A_{0\cdot001}$	For Inner Limits $A^1_{0\cdot025}$	For Outer Limits $A^1_{0\cdot001}$
2	1·386	2·185	1·229	1·937
3	1·132	1·784	0·668	1·054
4	0·980	1·545	0·476	0·750
5	0·876	1·382	0·377	0·594
6	0·800	1·262	0·316	0·498
7	0·741	1·168	0·274	0·432
8	0·693	1·092	0·244	0·384
9	0·653	1·030	0·220	0·347
10	0·620	0·977	0·202	0·317
11	0·591	0·932	0·186	0·294
12	0·566	0·892	0·174	0·274
13	0·544	0·857	—	—
14	0·524	0·826	—	—
15	0·506	0·798	—	—
16	0·490	0·773	—	—
17	0·475	0·750	—	—
18	0·462	0·728	—	—
19	0·450	0·709	—	—
20	0·438	0·691	—	—

TABLE VII

CONTROL LIMITS FOR STANDARD DEVIATION (S)

Number in Sample n	Lower Limits		Upper Limits		For Average Value of b_n
	Outer $B_{0\cdot001}$	Inner $B_{0\cdot025}$	Inner $B_{0\cdot975}$	Outer $B_{0\cdot999}$	
2	0·001	0·022	1·585	2·327	0·564
3	0·026	0·130	1·568	2·146	0·724
4	0·078	0·232	1·529	2·017	0·798
5	0·135	0·311	1·493	1·922	0·841
6	0·187	0·372	1·462	1·849	0·869
7	0·233	0·420	1·437	1·791	0·888
8	0·274	0·459	1·415	1·744	0·903
9	0·309	0·492	1·396	1·704	0·914
10	0·339	0·520	1·379	1·670	0·923
11	0·367	0·543	1·365	1·640	0·930
12	0·391	0·564	1·352	1·614	0·936
13	0·413	0·582	1·340	1·591	0·941
14	0·432	0·598	1·329	1·570	0·945
15	0·450	0·613	1·320	1·552	0·949
16	0·467	0·625	1·311	1·535	0·952
17	0·482	0·637	1·303	1·520	0·955
18	0·495	0·648	1·295	1·505	0·958
19	0·508	0·658	1·288	1·492	0·960
20	0·520	0·667	1·282	1 480	0·962

TABLE VIII

CONTROL LIMITS FOR COEFFICIENT OF VARIATION (v)

Number in Sample n	Lower Limits		Upper Limits		For Average Value C_n
	Outer $C_{0\cdot001}$	Inner $C_{0\cdot025}$	Outer $C_{0\cdot975}$	Inner $C_{0\cdot999}$	
5	55·07	10·32	0·449	0·271	1·489
6	28·54	7·22	0·468	0·293	1·379
7	18·37	5·66	0·485	0·312	1·309
8	13 37	4·73	0·500	0·329	1·261
9	10·50	4·13	0·513	0·345	1·225
10	8·68	3·70	0·526	0·359	1·199
11	7·44	3·39	0·537	0·372	1·177
12	6·54	3·15	0·547	0·384	1·160
13	5·87	2·95	0·557	0·395	1·146
14	5·35	2·79	0·566	0·405	1·134
15	4·93	2·66	0·574	0·415	1·124
16	4·59	2·55	0·582	0·424	1·116
17	4·31	2·46	0·589	0·433	1·108
18	4·07	2·38	0·596	0·441	1·102
19	3·87	2·31	0·603	0·449	1·096
20	3·70	2·25	0·609	0·456	1·091
21	3·55	2·19	0·615	0·463	1·086
22	3·41	2·14	0·620	0·470	1·082
23	3·29	2·09	0·625	0·476	1·078
24	3·19	2·05	0·630	0·483	1·074
25	3·09	2·02	0·635	0·489	1·071
26	3·01	1·98	0·640	0·494	1·068
27	2·93	1·95	0·644	0·499	1·066
28	2·86	1·92	0·648	0·505	1·063
29	2·79	1·89	0·652	0·510	1·061
30	2·73	1·87	0·656	0·515	1·059

The control limits are:

Inner limits at $D_{0\cdot025} \times \sigma$ and $D_{0\cdot975} \times \sigma$.
Outer limits at $D_{0\cdot001} \times \sigma$ and $D_{0\cdot999} \times \sigma$.

The average value of $\omega = \bar{\omega} = d_n \times \sigma$.
The factors for D and d_n are given in Table IX.
Where it is possible to use $\bar{\omega}$ directly, the limits may be calculated as follows:

Inner limits at $D^1_{0\cdot125} \times \bar{\omega}$ and $D^1_{0\cdot975} \times \bar{\omega}$.
Outer limits at $D^1_{0\cdot001} \times \bar{\omega}$ and $D_{0\cdot999} \times \bar{\omega}$.

These factors are given in Table X.

Control Chart for Variation of Range.—Using values as before, we are able to construct a control chart for the variation of range, from both σ and $\bar{\omega}$. The values are:

$\sigma = 0\cdot043$ and number of individuals in the sample $= 5$.

Inner limits : $D_{0\cdot025} \times \sigma = 0\cdot85 \times 0\cdot043 = 0\cdot03655$.
$D_{0\cdot975} \times \sigma = 4\cdot20 \times 0\cdot043 = 0\cdot18060$.
Outer limits : $D_{0\cdot001} \times \sigma = 0\cdot37 \times 0\cdot043 = 0\cdot01591$.
$D_{0\cdot999} \times \sigma = 5\cdot45 \times 0\cdot043 = 0\cdot23435$.

Average value $= \bar{\omega} = d_n \times \sigma = 2\cdot326 \times 0\cdot043 = 0\cdot1000$.

TABLE IX

CONTROL LIMITS FOR RANGE (ω) RELATIVE TO STANDARD DEVIATION (σ)

Number in Sample n	*Lower Limits*		*Upper Limits*		*For Average Value* d_n
	Outer $D_{0 \cdot 001}$	*Inner* $D_{0 \cdot 025}$	*Inner* $D_{0 \cdot 975}$	*Outer* $D_{0 \cdot 999}$	
2	0·00	0·04	3·17	4·65	1·128
3	0·06	0·30	3·68	5·05	1·693
4	0·20	0·59	3·98	5·30	2·059
5	0·37	0·85	4·20	5·45	2·326
6	0·54	1·06	4·36	5·60	2·534
7	0·69	1·25	4·49	5·70	2·704
8	0·83	1·41	4·61	5·80	2·847
9	0·96	1·55	4·70	5·90	2·970
10	1·08	1·67	4·79	5·95	3·078
11	1·20	1·78	4·86	6·05	3·173
12	1·30	1·88	4·92	6·10	3·258

TABLE X

CONTROL LIMITS FOR RANGE (ω) RELATIVE TO AVERAGE RANGE ($\bar{\omega}$)

Number in Sample n	*Lower Limits*		*Upper Limits*	
	Outer $D^1_{0 \cdot 001}$	*Inner* $D^1_{0 \cdot 025}$	*Inner* $D^1_{0 \cdot 975}$	*Outer* $D^1_{0 \cdot 999}$
2	0·00	0·04	2·85	4·12
3	0·04	0·18	2·17	2·98
4	0·10	0·29	1·93	2·57
5	0·16	0·37	1·81	2·34
6	0·21	0·42	1·72	2·21
7	0·26	0·46	1·66	2·11
8	0·29	0·50	1·62	2·04
9	0·32	0·52	1·58	1·99
10	0·35	0·54	1·56	1·93
11	0·38	0·56	1·53	1·91
12	0·40	0·58	1·51	1·87

Using the value of $\bar{\omega}$, found above, we have:

Inner limits: $D^1_{0 \cdot 025} \times \bar{\omega} = 0 \cdot 37 \times 0 \cdot 100 = 0 \cdot 037.$

$D_{0 \cdot 975} \times \bar{\omega} = 1 \cdot 81 \times 0 \cdot 100 = 0 \cdot 181.$

Outer limits: $D_{0 \cdot 001} \times \bar{\omega} = 0 \cdot 16 \times 0 \cdot 100 = 0 \cdot 016.$

$D_{0 \cdot 999} \times \bar{\omega} = 2 \cdot 34 \times 0 \cdot 100 = 0 \cdot 234.$

Connection between Standard Deviation (σ) and Range ($\bar{\omega}$).—For practical purposes the following table (Table XI) may be used, which shows the connection between the standard deviation (σ) and range ($\bar{\omega}$), so that where the one is known the other can be calculated.

TABLE XI.

No. in Sample	2	3	4	5	6	7	8	9	10
an . .	0·8862	0·5908	0·4857	0·4299	0·3946	0·3698	0·3512	0·3367	0·3249

Formula:

$$\sigma = a_n\bar{\omega} \text{ and } \bar{\omega} = \frac{\sigma}{an}.$$

Thus, in our example above where

$$\sigma = 0{\cdot}043,\ \bar{\omega} = \frac{\sigma}{an} = \frac{0{\cdot}043}{0{\cdot}4299} = 0{\cdot}1000 \text{ approximately.}$$

Mathematical Basis of Control Limits.—All the basic control limits for constructing Quality Control charts have been founded on the Gaussian frequency, the inner limits on the probability of the results for 1/40, i.e. 2·5 per cent. falling within $\pm 1{\cdot}96\sigma$, and for the outer limits on the probability of 999/1000, i.e. 99·9 per cent. falling within $\pm 3{\cdot}09\sigma$. Hence the notation $B_{0\cdot001}$, $B_{0\cdot025}$, etc., for the lower limits and $B_{0\cdot975}$ and $B_{0\cdot999}$, etc., for the higher limits.

Thus, for the calculation of the $A_{0\cdot025}$ limits the formula is as follows (Table V):

$$A_{0\cdot025} = 1{\cdot}96\sqrt{n} \text{ where } n = \text{the number of samples.}$$

For the calculation of the $A_{0\cdot001}$ limits:

$$A_{0\cdot001} = 3{\cdot}09\sqrt{n}.$$

For the calculation of the $A^1_{0\cdot025}$ limits:

$$A^1_{0\cdot025} = \frac{1{\cdot}96\,a_n}{\sqrt{n}} \text{ where } a_n \text{ has values as in Table X.}$$

For the calculation of the $A^1_{0\cdot001}$ limits:

$$A_{0\cdot001} = \frac{3{\cdot}09\,a_n}{\sqrt{n}}.$$

Size of Sample.—In an example where 1 defective was expected on an average, we should be on the watch for the frequency with which 4 or more defectives (see Table I) occurred, as this is likely to be an indication of change. It will be noted that this increase in defectives could be equivalent to doubling the proportion defective because, whereas with 1 defective expected 4 defectives should occur 1 in 50 times, an occurrence of 4 or more defectives 1 in 7 times is equivalent to an average of 2 defectives in the sample. By doubling the size of the sample so that 2 defectives on an average will be found, 6 or more defectives will be increased to a frequency of occurrence of 1 in 8·6 instead of 1 in 60, when the average number of defectives has increased to 3·3 or 65 per cent. This is a simple illustration of how the change in probability is affected by the change in the size of the sample.

Quality Control in Practice.—The greatest benefit is derived from Quality Control in its intelligent application in production at the machine, so that work can be checked whilst this is proceeding. A number of considerations need attention when it is first being installed. The chief of these are as follows:

(1) Tolerance on part should be wide enough to give reasonable spread on the charts.

(2) Personnel doing recording at early stages should be reliable.

(3) Run of job should be such as to last for good period.

(4) Job should be free from troubles which are not due to hold-ups or stoppages.

(5) Samples chosen should be measured within the period, i.e. shift, in which they are made.

(6) Dimensions chosen should be easily measurable with micrometer or dial gauge.

(7) Gauge should be capable of measuring to small subdivision of tolerance, say 5 to 10 per cent.

(8) Products, if similar, from a group of machines must be segregated and the recordings made separately.

Use of Data provided by Quality Control.—Data provided by Quality Control have two main purposes:

(1) To give information as to likely percentage defective from given machine, process, or supplier.

(2) To provide means of guiding producers as to the point at which quality of production changes, so that machine or process can be reset to give required quality. Procedure:

(1) Decide upon number of products or population which is to form sub-group to be sampled. Best choices are:

(*a*) One hour's run.

(*b*) Contents of given-sized container.

(*c*) So that sample forms 5 to 10 per cent. of sub-group.

(2) Decide upon number in sample. This should be between 4 and 10, and 5 is the best choice.

(3) Routine for taking sample may be as follows:

(*a*) Sub-group is taken aside and samples selected at random from sub-group.

(*b*) At selected time inspector takes the samples from machine as they are produced.

(4) Benefits of above two routines:

(*a*) Parts may be taken as representative of production between visits.

(*b*) Parts indicate condition of production at moment of sampling.

(5) Data sheets for Quality Control should be provided, giving information as follows:

(*a*) Part number of component.

(*b*) Name of component.

(*c*) Machine on which production is proceeding.

(*d*) Expected date of production.

(*e*) Selected sampling period and number in sample.

(*f*) Dimension checked.

(*g*) Drawing size of dimension checked with drawing tolerance.

(*h*) Measurements taken, columnised so that these can be entered for each sample.

(*j*) and (*k*) Parameters required, viz. total of samples, mean, range, and control limits.

(*l*) Inspector's signature.

(*m*) Signatures of personnel making components, e.g. operator, setter, etc.

(6) The measurements of the dimension concerned for each individual are taken.

(7) These measurements are added together and their sum divided by the number of samples to give the sample mean—$\bar{x}$.

(8) The smallest measurement in the samples is subtracted from that of the largest, thus giving the sample range.

(9) These parameters, i.e. sample mean of the samples and range of the samples, are entered on the data sheet and plotted on the control chart.

The plotting of the sample means and range of the samples is tested as given previously.

Quality control, whilst it aims at a perfect product, cannot of course attain it, for absolute perfection is impossible.

Imperfections resulting from causes which cannot be helped are known as defects occurring through "chance-variability" causes. A few of these are appended, and they are the reasons why we can never achieve perfection on any dimension.

(*a*) Clearance in guides and bearings of machine necessary for movement.

(*b*) Spring in machine parts and cutting tools.

(*c*) Vibration.

(*d*) Imperfections in cutting edges, though precision ground.

(*e*) Imperfections in raw materials (density, size, etc.).

(*f*) Irregularity of coolant supply, and imperfect mixing.

(*g*) Irregularity in machine speed.

(*h*) Differences in pressure transmitted to cutting edge by default of the operator or other agent.

(*i*) Irregularity in temperature of machine, tool, coolant, etc., and other causes which cannot readily be corrected, many of which are transient.

WORKS COST ACCOUNTS

Definitions.—*Costs* are the expenses incurred in producing goods for sale or providing a service.

Cost Accounts: Are the records which cover the above, arranged in such a way as to provide the information so that the best results can be obtained from the records.

Aims and Objects.—The chief aims and objects of Cost Accounts are:

(*a*) The determination of the expenses incurred as above so that selling price can be fixed.

(*b*) The analysis of the expenses incurred so that control over them can be made.

(*c*) The determination of departmental or sectional efficiency or waste.

(*d*) The provision of information which will show where economies can be effected, either in methods, tools, layout, design, or output.

(*e*) The comparison of actual costs with estimates made.

(*f*) To provide the management with data which will form basis for policy.

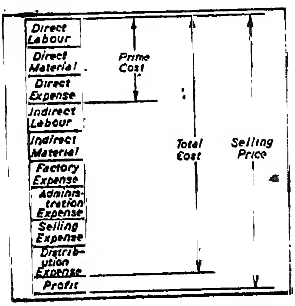


Fig. 1.—How cost is made up, showing the elements of cost.

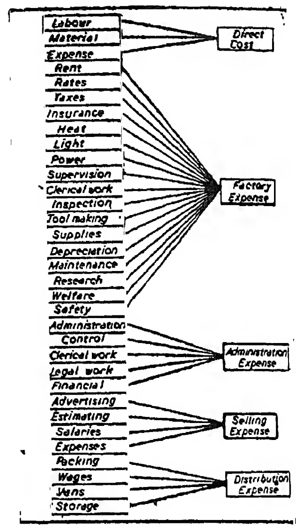


Fig. 2.—The elements of cost.

(*g*) The comparison of costs of production on any given type of plant as against some other type.

(*h*) The determination of inventory values as and when desired.

(*i*) To ascertain whether components can be purchased outside at a cheaper rate than internal production.

Costing as a Managerial Aid.—Costing is a vital aid to management, for it provides a valuable form of control as given in (*b*), (*c*), (*d*), (*f*), and (*g*) above. It serves as an important means of measuring departmental efficiency, aids in the formation of policy as to price, expenditure, labour remuneration, and budgetary control.

How Selling Price is Made Up.—The parts which go to make up a selling price are shown in Fig. 1. To the parts which go to make up the manufacturing cost we give the name Elements of Cost.

The Elements of Cost.—The elements of cost are those parts of expenditure incurred in production, administration, and selling the commodity (Fig. 2). They are as follows:

(1) Direct labour.
(2) Direct material. } These form Prime Cost.
(3) Direct expense.
(4) Overhead expense.

Direct Labour: Is all that expended in the production of the parts which can be so designated.

Direct Material: Is all that which is used to form the part.

Direct Expense: Is any such which can be designated as being incurred in the actual production of the parts.

Overhead Expense: Is all the expense incurred in the production, administration, and distribution which cannot be designated to any specific cost unit. It is again divided into:

Indirect Labour Cost.
Indirect Material.
Factory Expense.
Administration Expense.
Selling Expense.
Distribution Expense.

Indirect Labour: Is all that which cannot be specifically charged to any particular cost unit. It includes such labour as that of foremen, shop labourers, clerks, maintenance men, storekeepers, etc.

Indirect Material: Is all that which cannot be traced as part of the product. It includes such supplies as oil, rag, small tools, etc. Sometimes material which goes into the product in minute quantities, such as solder, lacquer, paint, etc., but which is difficult to analyse as to quantities, is counted under this head.

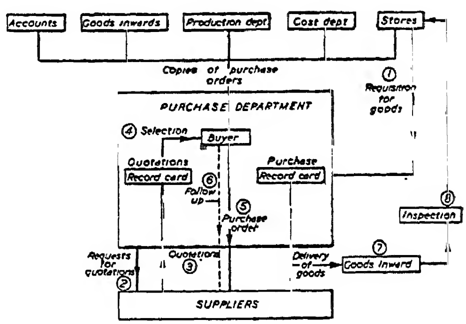


Fig. 3.—Quotation and order procedure.

Factory Expense: Is all the expenditure necessary for the efficient operation of the production unit. This expense includes the following:

Rent, rates, taxes, insurance, legal work, etc., which can be apportioned as chargeable to the factory.

Services such as heat, light, power, gas, compressed air, etc., used in the furthering of production.

Indirect labour such as supervision, shop clerical work, so-called non-productive labour such as inspection, tool-making, etc.

Consumable goods as above.

Depreciation of machines, tools, plant, and buildings.

Maintenance of machines, tools, plant, and buildings.

Experimental and research work.

Welfare and safety.

Administration Expense: Is all that is incurred in the administration and control of the organisation. Examples of this are:

Rent, rates, taxes, etc., as above, but chargeable to the administration offices.

Services, etc., used in the heating, lighting, and ventilation of the administration offices.

Wages and salaries of clerks, departmental managers, accountants, directors, executives, etc.

Cost of legal work.

Financial and other charges.

Selling Expense: Is all that incurred in the cost of securing orders for the product. It includes advertising; cost of estimating and tendering; wages and salaries of managers, salesmen, travellers, etc.

Distribution Expense: Is all that incurred in the distribution of the product from the dispatch point to the customer. It includes the wages of warehousemen, dispatch clerks, labourers, van drivers, etc.; cost of packing materials; finished stores expenses.

Costing Methods.—The following are the chief methods of costing:

Job Costing.
Unit Costing.
Process Costing.
Composite Costing.
Operation Costing.
Operating Costing.
Standard Costing.

Job Costing: This is of two kinds, viz. "Contract" and "Batch." Contract costing is used for contracts undertaken by the organisation, and is used by structural and constructional engineers, builders, etc. Batch costing is used for costing of batches from which unit costs can be determined. See page 1054 for method of operating.

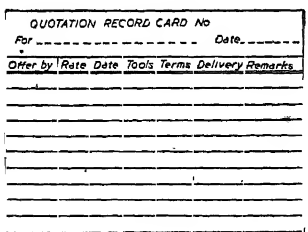


Fig. 4.—Card showing quotations submitted for a given enquiry.

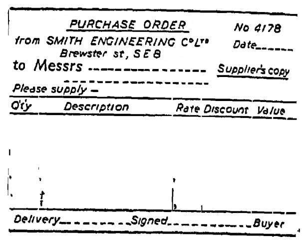


Fig. 5.—A purchase order form. (Supplier's copy).

Unit Costing: Is used for the determination of the cost of the unit of production where production is continuous and the units are identically the same. See page 1056 for method of operating.

Process Costing: Is a means of costing the products of a continuous process which are produced in bulk and which are usually identical in form if not in size or shape. Examples: metals, cement, gas, rubbers, etc. See page 1056 for method of operating.

Composite Costing: Is used for the costing of assembled components which make a composite whole. The cost of the components is usually determined by one of the other methods, and that of the assembly by the combination of these costs together with that of the assembly. See page 1057 for method of operating.

Operation Costing: Is a method used for costing by operations where parts are made by mass production or repetitive manufacture. See page 1057 for method of operating.

Operating Costing: Is used for the determination of the costs of services such as omnibus, tramways, railways, electricity, etc. See page 1057 for method of operating.

Standard Costing: Is a means of costing by the application of predetermined standards based upon a given degree of efficiency and the operation of up-to-date manufacturing standards as to rate-fixing, job standardisation, and budgetary control. See page 1057 for method of operating.

The Cost Department

Functions.—(*a*) To provide cost statements as required for aid in management control.

(*b*) To present costs of the various elements as required.

(*c*) To maintain records of the various elements.

(*d*) To maintain and allocate the records of the overhead expenses.

(*e*) To advise on the basis of ascertained cost the fixing of the selling price.

Organisation.—The close linking of the cost department with all other departments is of prime importance to the success of the costing system. It must act as a service department for the management to guide it in their decisions by the provision of figures that are true and reliable. By reason of the data which it records, the costing department provides the designs department with a ready means of checking the value of making changes in designs and of new developments. Its connection with the general accounts department is either subsidiary or separate. In either case it has to work closely with that department in order that records of purchases, sales, monetary transactions, etc., which have to be taken by the costing department, shall be readily available to both. In some small organisations the accounts department includes costing as one of its functions, but in the larger organisations it is a separate function with close association, and this is preferable. The accounts department, however, should

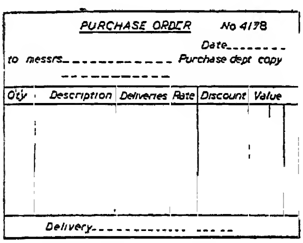


Fig. 6.—Purchase department's copy of the purchase order.

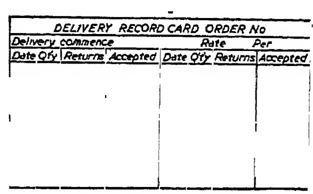


Fig. 7.—Record card for deliveries made on a given order.

retain some control over the costing department for the purpose of general auditing.

With each of the production departments of the organisation close co-operation is necessary to success, and there are reciprocal duties which must be performed to this end. The whole costing organisation must link with the production functions in order that information, data, and operating figures can be collected. A routine must be established which should have the following as the minimum reciprocal functions.

Functions of Production Departments in Relation to Costing

Purchasing.—(*a*) To inform costing department of the costs, and fluctuations thereof, of purchased goods.

(*b*) To provide costs of bought-out goods for comparison with factory-made products.

(*c*) To advise on current value of stock for purposes of inventory valuation.

Production Department.—(*a*) To issue production schedules in time for cost department to prepare cost machinery.

(*b*) To co-ordinate efforts of personnel responsible for records passed to cost department.

(*c*) To notify changes in production schedules.

(*d*) To advise cost department as each batch passes through the various stages of manufacture and notify date of completion of each batch.

(*e*) To notify changes of method or deviation from standard laid down.

(*f*) To approve quantities notified as those when job is closed down.

Shop Superintendents, Foremen, etc.—(*a*) To ensure that all responsible observe rules laid down for operation of existing cost system.

(*b*) To approve quantities notified as those when job is closed down.

(*c*) To supervise all clerical assistance under his control who provide records required by the cost department.

(*d*) To notify changes of method or deviations from standard laid down.

(*e*) To see that records as to repairs, tool breakdowns, and other defects are properly kept.

Inspection Department.—(*a*) To notify quantities of good products passed at each stage.

(*b*) To notify quantities scrap or wasted.

(*c*) Check quantities of good raw material or bought-out finished parts passed to stores.

(*d*) Verify that above are to specification.

(*e*) To notify quantities of good products passed to dispatch department for customer.

Planning Department, Rate Fixers, etc.—(*a*) To notify costing department of standards to which labour should conform as to remuneration, output, quality, etc.

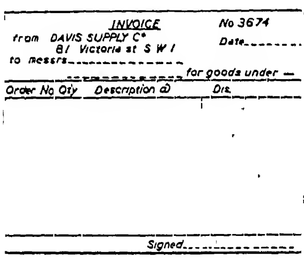


Fig. 8.—A typical invoice.

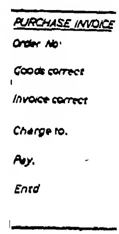


Fig. 9.—Rubber stamp for invoices.

(*b*) To notify changes in labour rates which will be affected by changes of method or operation.

Shop Clerical Labour.—Foremen's clerical assistants, timekeepers, etc., play an important rôle in the operation of the costing system, and to this end must be thoroughly trained to ensure efficiency in the compiling of the records concerned. The work done by these is as follows :

(*a*) Issue of job tickets, etc., to operators.

(*b*) Recording of starting and finishing times for jobs.

(*c*) Recording of quantities issued and made at each operation.

(*d*) Recording of productive and non-productive times.

Sometimes timekeepers are under the direct control of cost department head, but more often responsible to factory management.

Storekeepers, Stores Ledger Clerks, etc.—(*a*) To record accurately quantities received either from supplier or shop.

(*b*) To record accurately quantities issued for each job, operation, or process.

(*c*) To notify accurately all stores credits and debits occurring in any job, operation, or process.

(*d*) To ensure that nothing is issued or received without requisite authorisation.

(*e*) To dispatch requisitions promptly at recognised intervals to the cost department.

Wages Department.—(*a*) To calculate remuneration due to operators and transmit records of these to cost department.

(*b*) To record wages and salaries of non-productive labour for issue to cost department.

(*c*) To record commissions, etc., paid to outside staff, etc.

Duties of Cost Personnel.—Whilst with a properly routinised cost system the clerical labour employed can be relatively unskilled, the chief personnel should be well trained in accountancy. From the relatively unskilled clerical labour the chief attributes required are accuracy, understanding of the routine, and speed. The chief of the department should have at least a familiarity with the processes costed, and should preferably be able to judge of the efficiency of the various departmental operations. A knowledge of the particular industry as a whole is an advantage, as is an ability to devise suitable systems.

Departmental Routine for Costing.—Independently of whatever costing system is in use a definite routine must be laid down for each department, so that records pertaining to the functions of that department can be passed to the cost department.

Purchasing Department.—We commence with this department, as it is responsible for the introduction into the factory of the raw material, etc., which serves as the basis of production. Much which is said here has close connection with the subject of Production Control so that reference to this section will be advisable as we proceed. At the request of the Production Department or Stores, the Purchasing Department places orders on outside suppliers for goods to be used either as direct or indirect material. Material so purchased will be of various kinds, and a system of classification is of prime importance as an aid to quick reference. One form of classification can be related to the kind of stock the material forms, as:

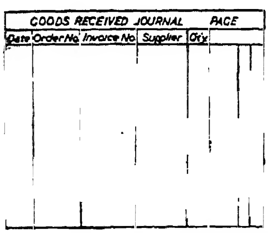


Fig. 10.—A typical page from the goods received journal.

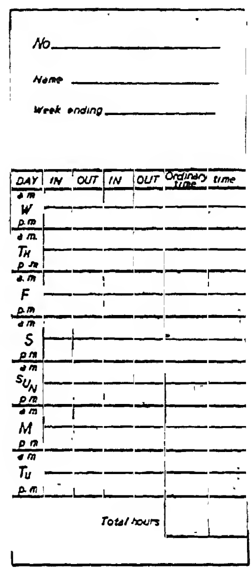


Fig. 11.—Time card (obverse side for time booking).

Raw Material: Which is in a natural or partially manufactured condition upon which work is done to form the product. It includes bar, strip, castings, etc.

Part-finished Stock: Is purchased in a semi-finished state and requires further work. These would include parts sub-contracted out but requiring further work.

Finished Goods: Are those purchased in a condition which requires no further work before assembly to product; such items are screws, nuts, bolts, washers, pressings, mouldings, etc.

Consumable Goods: Are those used in performing certain services for the maintenance of the plant—oil, rags, coal, etc.

Tools: This may include everything from a small drill to an expensive press tool.

General Supplies: These are non-consumable goods which at the same time are not tools, and includes brooms, brushes, pencils, stationery, etc.

Wherever possible a code of classification of the goods purchased should exist with the object stated above—quick reference and also systematic recording and the avoidance of error. By this means the pricing of all materials by the Cost Department becomes simplified. Many codes suggest themselves and we give examples below:

Codes for Classifications of Material.—(1) A simple numbering code so that raw material is classified 100–199, part finished stock 200–299, etc. This will be found to lead to large unwieldy numbers and is not to be recommended.

(2) An alphabetic code in which the various kinds of material are still further subdivided into their particular kinds, such as brass rod—B.R.; mild-steel rod—M.S., with further subdivisions to denote size or shape, thus:

B.R.8 = $\frac{1}{2}$-in.-dia. brass rod. B.R.9 = $\frac{9}{16}$-in.-dia. brass rod.
M.S.4 = $\frac{1}{4}$-in.-dia. mild-steel rod. C.U.10 = $\frac{5}{8}$-in.-dia. copper rod.

This system has much to recommend it, particularly if the prefix letters bear relationship to the name of the material.

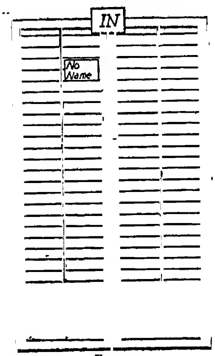


Fig. 12.—A typical clock-card rack.

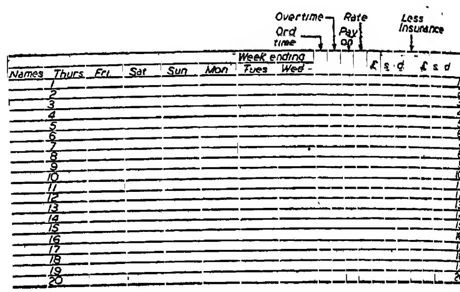


Fig. 13.—Wages sheet from dial-type recording clock.

Most finished goods will have part numbers which are allocated by the Drawing Office.

Purchase Department Procedure.—The procedure likely to take place in regard to the purchase of supplies is as follows (Fig. 3):

(1) Requisition from Production Department or Stores for outside supplies (see Fig. 6, Production Control Section).

(2) Request for quotation from various potential suppliers.

(3) Entry of prices and delivery dates quoted, on Record Card (Fig. 4).

(4) Selection of source of supply from above.

(5) Placing of Purchase Order (Fig. 5). Copies to Accounts, Cost Department, Production Department, Goods Inwards, Goods Receiving, Stores.

(6) Follow up, if necessary, to secure delivery (see Fig. 7, Production Control Section).

(7) Receipt of Goods (see Fig. 29, Production Control Section).

(8) Inspection of Goods.

(9) Entry of Delivery, either: (*a*) on Purchase Department, copy of Purchase Order (Fig. 6), or (*b*) on Delivery Record Card (Fig. 7).

(10) Adjustment of Credit for returns and exchanges.

(11) Checking of Invoices (Fig. 8) covering transaction with supplier.

Checking Purchase Invoices.—It should be the duty of the Purchase Department to check invoices submitted for purchased goods. When the calculations are checked and found to be correct, the invoice should be impressed with

a stamp (Fig. 9) with the appropriate spaces filled in by the Buyer or his staff. The stamp provided should give the following information :

(a) Order number.
(b) Goods correct.
(c) Invoice checked and found correct.
(d) Cost element to which allocated.
(e) Signature authorising payment.
(f) Signature of person making entry into Goods Received Journal.

The entries (a), (b), (c), and (d) are made by the Purchase Department. The invoice is then passed to the Accounts Department, who authorise payment and make entry in Goods Received Journal (Fig. 10).

Stores.—Stores routine in dealing with receipt of goods both bought out and internally produced is outlined under Material Control in the Production Control Section (see p. 960).

Remuneration of Labour: Wages and Time Booking.—The remuneration of labour and the booking of the time employees are engaged in the factory or on various jobs are vital elements in the cost system, and a thorough understanding of the methods employed is necessary before showing how the various Costing Systems are affected.

Remuneration of Labour.—There are principally two methods of remunerating labour, viz. (a) Time (or day-rate) wages; (b) Payment by results. Both methods are outlined in the section on Wages Incentives (p. 1061).

Wages.—The compilation of the amounts due to labour is invariably the duty of the Wages Department, who use the data obtained from the time-booking records and the piece-work methods. The methods employed in checking timekeeping and for the time-booking of jobs affect the form of entries used by the Wages Department.

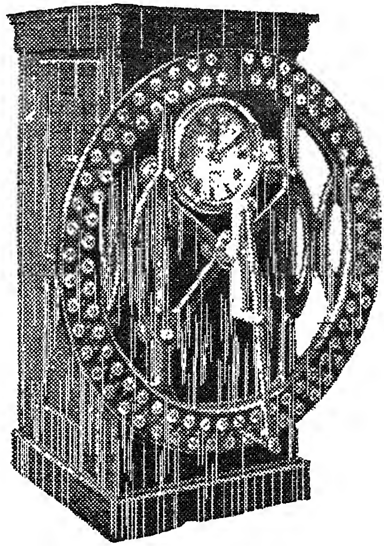


Fig. 14.—International automatic dial time recorder.

Timekeeping.—There are four principal methods employed to checking timekeeping :

(1) Checks.
(2) Card clocking.
(3) Dial recording.
(4) Key recorders.

(1) *Checks:* This is a very old method and is now practically extinct. It consists in providing each employee with a metal disc or check bearing his or her number, the disc being moved from a hook on a board upon arriving at the factory gate and passing it into an appropriate receptacle according to whether the worker is early or late. Entries are accordingly made in a register by the timekeeper, after which the disc is given out to the employee for depositing when leaving the factory. Variations on this method are possible, but newer methods render it out of date.

(2) *Card Clocking:* In this method a printed card (Fig. 11) is issued to each employee, which lasts one working week. The times of entering and leaving the factory are stamped thereon in appropriate columns against the day. A rack is

provided on either side of the clock (Fig. 12) in each of which the cards are placed, the rack nearest the works exit being that in which the cards rest when the employee is not at work, the other providing a means of retaining the card when the employee has entered the works. This also forms a ready means of ascertaining absentees and latecomers. Some types of clocks stamp the normal times in black ink and the times of late arrival, overtime, or early departure in red. This provides a ready means of dealing easily with such deviations from the normal, and may have a moral effect on the worker. Most clocks depend upon the registration of the card in a stop which rises vertically each day and upon a shift key which sets the card in relation to the type for "in" and "out" stampings.

(3) *Dial Recorders:* In this type a weekly sheet (Fig. 13) is inserted which is suitable for filing to form a wages book. The clock (Fig. 14) has an arm which is capable of rotation to a given number set in a large circular dial. Against each number, which is that corresponding to the number of the employee, is a hole into which a plunger on the end of the rotary arm is pressed, this causing the stamping mechanism of the clock to record the time of arrival or departure of the employee. This is a very good system. The recorder is capable of making records in the correct position, notwithstanding the irregularity of the times of making the stamping.

(4) *Key Recorders:* In this method each employee is given a key (Fig. 15) which, when inserted into the recorder and given a quarter of a turn, makes the

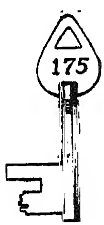


Fig. 15.—A typical key from a key time-recording clock.

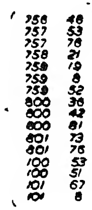


Fig. 16.—Type of time recording made by a key clock.

necessary registration of time. The keys are hung on appropriate boards and replaced when the recording is made. An infinite number of keys can be available, and the time taken to make the recording very small, so that only one clock is needed for many employees. The method of stamping the time (Fig. 16) does not, however, lend itself very well as a method of making wage records.

Compiling Time Wages.—The methods of compiling time wages from the timekeeping records can be clearly followed in each of the two chief forms of clocking (Figs. 11 and 13).

Time Booking.—For the purpose of compiling labour costs a number of systems exist of recording the time of starting and finishing, particulars of the job and a calculation of the time spent on each job worked on by the employee. The systems used for this purpose fall chiefly into the following:

(1) Time sheets.
(2) Time analysis.
(3) Job cards.
(4) Time-recording instruments.

(1) *Time Sheets* (Fig. 17): These may be daily or weekly, and are in any case filled in by the employee, giving particulars of the time spent on each job. This is not a very good system, depending, as it does, upon the conscientiousness of the employee in returning accurate figures with correct particulars as to job number, etc.

(2) *Time Analysis* (Fig. 18): This is a more reliable system in which a clerk enters upon a specially ruled analysis sheet the times of starting and finishing jobs, the job number, and the time spent. The use of rubber stamps for certain set times, with suitable entries for times spent also in the factory, makes the sheet

suitable for use as a complete time analysis. The whole sheet is self checking, as can be seen.

(3) *Job Cards* (Fig. 19): In this system job cards are made out either by the Production Department or the foreman's shop clerk for issue on each job. The card may serve as a good means of issuing full instructions about the job or merely (see Fig. 12, Production Control Section) as a method of recording the quantities made on each batch in conjunction with the time entries on the wages analysis (Fig. 18 above). The job card should follow the work round the shops until the parts are inspected, quantities good and scrap being entered for payment. Arrangements must be made to record the times spent so that a complete check can be made to see that this agrees with the timekeeping records of the time spent in the factory. This of course is fully covered in the wages analysis sheet. Another method is to use the reverse side of the clock card (Fig. 11), as shown in Fig. 20. By this means time on each job can be recorded, the total agreeing at the end of the week with that on the obverse side (Fig. 11).

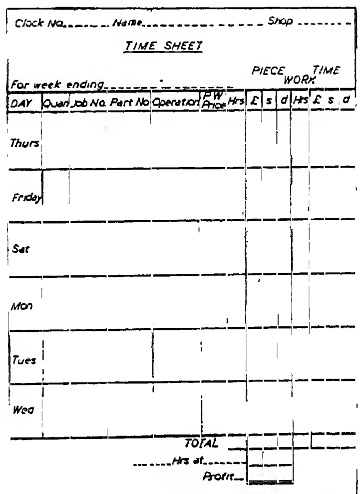


Fig. 17.—A typical time sheet.

Factories having large numbers of job cards to deal with will find the mechanical tabulating machines very useful. The chief of these are the Hollerith (Hollerith Tabulating Machines) and the Powers (Powers-Samas Accounting Machines, Ltd.). The staffs of these two organisations are always available to give advice on any aspect of this subject.

(4) *Time Recording Instruments*: By means of these it is possible to make accurate time recordings of starting and finishing times. A printed card is used, giving particulars of the job, the operator, and the operation performed (Fig. 21). The card is inserted into the recorder (Fig. 22) so that the appropriate column and line is accurately spaced by means of an edge gauge and a pointer. A depression of the lever records the time. A number of such recorders exist.

Overheads.—The compilation of overhead expenses and their allocation to the product is a fundamental part of the Cost Department's duties. According as the importance of separating the expenses down into their finest parts to obtain greater accuracy of cost of the product, so will the system of classifying, compiling, and allocating be more or less complex. These notes serve to show what is necessary in most modern undertakings of moderate size in order that the expenses shall be pretty accurately apportioned. How necessary it is to go to great lengths to obtain this accuracy will depend on several factors:

(*a*) Kind of work undertaken.
(*b*) Importance of covering full expenses accurately.
(*c*) Ability to obtain suitable cover.
(*d*) Tendering.

So far as (*a*) is concerned, the kind of work done by the undertaking affects the importance of the accuracy where:

(1) Different products are made in separate departments or factories. In this case it is necessary that each kind of product is charged fully with its own departmental or factory overhead.

(2) Continuous or process production occurs. It may not be so important to

obtain completely accurate overhead classification, unless this is required for checking departmental efficiency—a very important use.

For (*b*) the importance occurs chiefly in job costing, where it is very necessary that each job be accurately costed so that full cover is obtained without making the product dear and unable to meet the market.

Where, as in (*c*), the market price of the product easily covers the cost of production lumped together as a whole, the accuracy is not so important.

For (*d*) the purpose of tendering for new work on a competitive basis, it is vital that accurate records exist.

However, it should not be overlooked that one of the chief objects of compiling accurate overhead costs records is that of enabling the management to control these costs by comparison.

Classification of Overhead.—The best way of compiling overhead expenses is by a classification or subdivision of all the possible or most important of these by means of a heading to which all the appropriate expense can be charged.

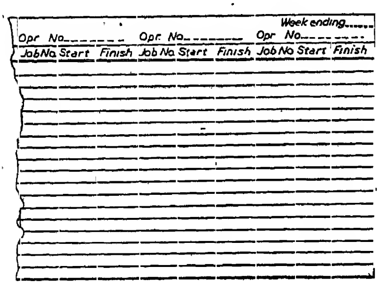


Fig. 18.—Time analysis sheet.

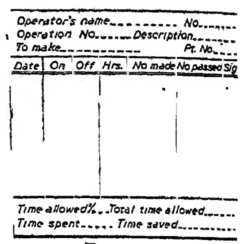


Fig. 19.—Job card.

The chief main division of Overhead is into Fixed and Variable Charges.

Fixed Charges: Are those which remain substantially unchanged regardless of the volume of production. They consist of rent, rates, taxes, depreciation, interest, etc.

Variable Charges: Are those which vary with the volume of production and includes indirect wages, power, etc.

For the purpose of familiarising the classifications of overheads to all those employees who require to deal with them, a system of symbols is necessary. To such symbols, it is common to give the name "Standing Orders." A number of systems are in use, of which we give various examples below.

Standing Order Systems.—*Example I:* A simple system is to classify each of the charges by a number and prefix the number by an alphabetical symbol which denotes the department incurring it.

Thus, the departments are denoted:

A = Stores.
B = Packing department.
C = Foundry.
M = Machine shop, etc.

Overhead charges are denoted:

(1) Repairs to plant, fixtures.
(2) Repairs to machinery.
(3) Repairs to tools.
(4) Labouring.
(5) Waiting time, etc.

Thus :

A.4 covers stores labouring.
B.2 covers repair of tools for the packing department.
C.1 covers repair of foundry plant.
M.5 covers waiting time incurred in the machine shop.

This system is capable of wide expansion to cover more definite charges. Thus :

11 = Repair to factory buildings.
12 = Repairs to office buildings.
13 = Repairs to transmission plant.
14 = Repairs to lighting equipment, etc.
21 = Repairs to milling machines.
22 = Repairs to automatics, etc.
51 = Waiting for drawing.
52 = Waiting for instructions.
53 = Waiting for tools, etc.

Example II : Another simple system is to give letters to the overhead charges and to number the shops, with further subdivisions or more specific charges. Thus, simply :

R = Repair.
W = Waiting time.
L = Labouring.
B = Breakdown, etc.

The shops are numbered as required, more specifically :

R.1 = Repairs to factory buildings.
R.2 = Repairs to office buildings.
W.1 = Waiting for drawing.
W.2 = Waiting for instructions, etc.

Thus :

R.1/1 = Repair to foundry building, where /1 = foundry.
W.2/3 = Waiting for instructions in the machine shop, where /3 = machine shop.

Example III : A more complex, though very comprehensive system is to give each charge its own number, and either prefix the number by an alphabetical symbol for the department or suffix it with a number for the department, i.e. 25/6 = waiting time in machine shop No. 6.

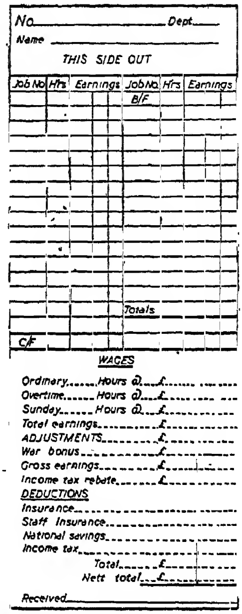


Fig. 20.—Reverse side of time card (Fig. 11) showing spaces for recording earnings.

Chief Overhead Charges.—Table I shows the chief overhead charges subdivided into Fixed and Variable Charges, with remarks applicable to each.

Allocation of Overhead.—The allocation of the overhead to the correct charge is of vital importance to the success of any system. So far as the charge is incurred in the production of the goods, its allocation to manufacturing overhead is simple—thus, all charges occurring in the process from raw material to finished goods and all charges concerned with the instruments for this, buildings, plant, or machines, are easily recognisable as production overheads. The same is true of Administration and Selling Charges. In the more specific allocation to department or Standing Order, skill has to be exercised to make this correctly. To this end it is useful to publish for the guidance of those concerned a number of rules such as the following :

Rules for the Allocation of Overhead.—(1) The allocation must only be made with the authority of the person concerned, either the chief accountant for capital charges, the sales managers for selling charges, or the shop foreman for those chargeable to his department.

(2) Care must be taken to allocate the charge against the department incurring it, regardless of the department which actually is affected by it.

Thus, "Waiting for Tools" may be chargeable either to the Tool Stores, Jig and Tool Drawing Office, Tool Room, or Purchasing Department.

(3) Where labour time has to be booked against a Standing Order, the permission of the correct authority must be obtained. This is necessary to avoid the danger of time being booked against an overhead which should more correctly be booked against a production charge.

Collection of Overhead Expenses.—The collection of overhead expenses is carried in two methods:

(*a*) By direct book-keeping whereby accounts exist for items directly allocable to given expenses, either labour or material.

(*b*) By booking of time for labour charges or issue of requisition for material.

TABLE I

VARIOUS OVERHEAD CHARGES

(*a*) *Fixed Charges*

(1) Rent of land and buildings.
(2) Rates (local authorities).
(3) Insurance.
(4) Depreciation: (*a*) buildings; (*b*) plant and machinery.
(5) Obsolescence.
(6) Salaries.
(7) Capital charges—Interest.

(*b*) *Variable Charges*

Works Charge	*How Collected*	*How Apportioned*
Labour:		
Waiting time	Time booking on S.O.	To department causing.
Training new labour	,, ,, ,, ,,	To department using labour.
Stores	,, ,, ,, ,,	,, ,, ,, ,,
Time-keeping	,, ,, ,, ,,	,, ,, ,, ,,
Inspection	,, ,, ,, ,,	,, ,, ,, ,,
Shop clerical labour	,, ,, ,, ,,	,, ,, ,, ,,
Holidays with pay	On special account.	General overhead.
Sickness	,, ,, ,,	,, ,,
Shop labouring	Time booking on S.O.	To department using labour.
Cleaning machines	,, ,, ,, ,,	,, ,, ,, ,,
Overtime	,, ,, ,, ,,	,, ,, ,, ,,
Faulty work	,, ,, ,, ,,	,, ,, ,, ,,
Supervision, foremen, etc.	On special account.	,, ,, ,, ,,
Maintenance and repairs:		
(*a*) Buildings	Time booking on S.O.	General overhead.
(*b*) Plant and machinery	,, ,, ,, ,,	,, ,,
(*c*) Transport (internal)	,, ,, ,, ,,	,, ,,
(*d*) Fixtures, bins, etc.	,, ,, ,, ,,	To departmental expense.
(*e*) Tools	,, ,, ,, ,,	,, ,,
(*f*) Office equipment	,, ,, ,, ,,	General overhead.
Services:		
(*a*) Power	On special account.	General overhead.
(*b*) Heating	,, ,, ,,	,, ,,
(*c*) Lighting	,, ,, ,,	,, ,,
(*d*) Fire protection	,, ,, ,,	,, ,,
Miscellaneous:		
Welfare, first aid and safety	On special account	General overhead.

TABLE I—*continued*

Works Charge	*How Collected*	*How Apportioned*
Insurances . . .	On special account.	General overhead.
(*a*) National.		
(*b*) Workmen's Compensation.		
(*c*) Employers' Liability		
(*d*) Plant (boilers, etc.).		
(*e*) Plant breakdown.		
Experimental work .	On special account.	General overhead.
Designing . . .	,, ,, ,,	,, ,,
Drawing Office ,, .	,, ,, ,,	,, ,,
Production, etc., Departments. . . .	,, ,, ,,	,, ,,
Supplies, consumable goods, small tools, waste oil, etc. . . .	As per requisition.	To departmental expense.
(*c*) *Variable Charges—Administration*		
Salaries of managers, executives, clerical labour, etc. . . .	On special account.	General overhead.
Office services (lighting, heating, etc.) . .	,, ,, ,,	,, ,,
Repairs and Maintenance	,, ,, ,,	,, ,,
(*a*) Buildings.		
(*b*) Power plant.		
(*c*) Equipment.		
Legal and professional services	,, ,, ,,	,, ,,
Trade affiliations and investigation . . .	,, ,, ,,	,, ,,
Stationery and supplies .	,, ,, ,,	,, ,,
Postage and telephone .	,, ,, ,,	,, ,,
Royalties . . .	,, ,, ,,	,, ,,
(*d*) *Variable Charges: Distribution*		
Packing (including labour)	On special account.	Distribution overhead.
Warehousing (including labour) . . .	,, ,, ,,	,, ,,
Equipment (hoists, cranes, etc.) . .	,, ,, ,,	,, ,,
Transport (including labour and taxation) .	,, ,, ,,	,, ,,
Repairs and maintenance:		
(*a*) Warehouse and packing department . .	,, ,, ,,	,, ,,
(*b*) Equipment . .	,, ,, ,,	,, ,,
(*c*) Transport . .	,, ,, ,,	,, ,,
(*d*) Tools . . .	,, ,, ,,	,, ,,
Supplies: Packing material, stationery, etc. .	,, ,, ,,	,, ,,
Services—lighting, heating, etc. . . .	,, ,, ,,	,, ,,
(*e*) *Variable Charges: Sales*		
Salaries and commissions .	On special account.	Sales overhead.
Travelling expenses .	,, ,, ,,	,, ,,
Advertising . . .	,, ,, ,,	,, ,,
Demonstrations . .	,, ,, ,,	,, ,,
Estimating . . .	,, ,, ,,	,, ,,
Office services—lighting, heating, etc. . .	,, ,, ,,	,, ,,

Direct Accounting of Overhead Expenses.—A typical extract from an expense account is shown in Fig. 23, which is for the Distribution Overhead. Entries are made on to this account for the various journals covering each of the expenses items in this overhead.

Booking of Indirect Labour Costs.—A simple method of booking indirect labour costs is given in Fig. 24, which shows an overhead charge card for Waiting Time in a given department. The data recorded is as follows:

(*a*) Description of overhead charge.
(*b*) Standing Order number.
(*c*) Department against which chargeable.
(*d*) Clock number of operator.
(*e*) Name of operator.
(*f*) Time.
(*g*) Rate.
(*h*) Cost.
(*i*) Reason.
(*j*) Signature of supervisory staff.

Wages Analysis Sheet.—An efficient method of ascertaining weekly costs of indirect labour is by the wages analysis sheet (Fig. 25). Thereon are summarised the amounts shown for each department on the Overhead Charge Cards.

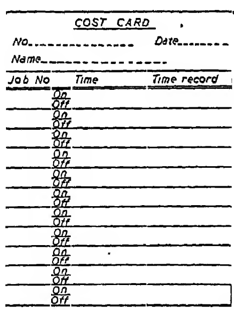


Fig. 21.—A cost card for use with a time recorder (Fig. 22).

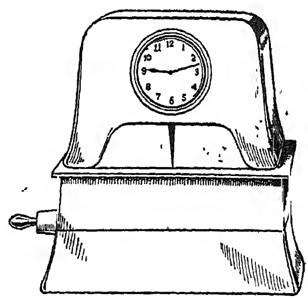


Fig. 22.—A typical time recorder.

Charging of Indirect Material.—This is made by either of the two methods enumerated above, that is (*a*) by the entry into the expense account as shown by the rubber-stamp impression on the invoice (Fig. 9), or (*b*) by entry from indirect material requisitions shown in Fig. 26, on which the cost of the material so used is extended and entered into the expense account. The latter method is imperative for the accurate collection of costs for departmental overheads.

Depreciation, Obsolescence, and Interest.—The correct determination of values for the items of depreciation, obsolescence, and interest on plant are important aspects of overhead accounting.

We define each term as follows:

Depreciation: Is the loss of life, and therefore value, of an asset, due to wear, tear, abuse, the elements, and the passage of time.

Obsolescence: Is the loss of value of plant and machinery through economic deterioration due to invention or improvement of design.

Interest on Plant: Is a cost due to the loss incurred by the withdrawal of the capital cost from other forms of investment.

DISTRIBUTION EXPENSE						
Date		Invoice No	Order No			
1944 Feb 3	To packing material A Smith Ltd	1736	D 467	34	6	10
	Tyres for Van W Browne & Co	921	D476	8	3	9
	Repairs to Hoist 9/D1	—	—	12	10	3
	Packing cases J Robinson & Son	864	D321	87	5	4

Fig. 23.—A page from the expense account journal for the distribution overhead.

Causes of Depreciation.—These are five in number:

(1) Wear and tear.
(2) Exceptional damage or deterioration.
(3) Limitation of use.
(4) Inadequacy.
(5) Obsolescence.

(1) *Wear and Tear:* Is limited by care and attention through adequate maintenance methods. Natural causes are effective through weather, physical changes, and fatigue due to the passage of time. The estimation of the expectancy of life having regard to these factors plays an important part in the value to be assigned to the rate of depreciation.

(2) *Exceptional Damage or Deterioration:* Is always possible but more likely in some types of plant. Insurance is undertaken for the purpose of covering this.

(3) *Limitation of Use:* Depends upon (*a*) the possibility of changes in design in the product and (*b*) cessation of demand for the product and therefore the type of plant or process.

(4) *Inadequacy:* Is the term used to cover the degree of possibility of the plant becoming inadequate due to increased volume of work or change of design demanding increased capacity.

(5) *Obsolescence:* Covers the complete range of possibility of progress in invention, scientific development, and economic change whereby the machine or plant becomes economically obsolete. It is obvious that a competitor having a machine of similar type but of greater economic value renders the ownership obsolete and uneconomic.

ON COST CHARGE No. Dept. W.E.										
Opr. No.	Date	On	Off	Total	E.T.C. No	Work from job	Value	REASON	Due to dept.	Signature

Fig. 24.—Overhead cost card.

Week ending												
Department	Productive	Non Productive	Re-distribution	1	2	3	4	5	6	7	8	9

Fig. 25.—Wages analysis sheet.

Physical Life of Plant.—This is estimated by judgment, experience, and existing records available about similar types of plant and mathematical determination from mortality records of the types. The values given to depreciation are reckoned as rates per cent., covering amount to be written off yearly from original capital cost or other depreciation

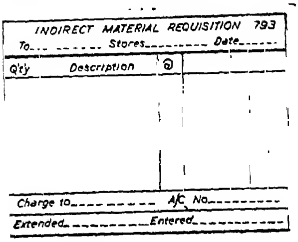


Fig. 26.—Indirect material requisition.

basis. Table II shows the rates in common use.

Basis of Depreciation.—There is no uniformity of method for measuring the amount of depreciation for a given piece of plant or machinery. Four bases exist for this purpose:

(1) Cost.
(2) Cost and maintenance.
(3) Replacement or reproduction cost.
(4) Existing value.

(1) *Cost Basis:* This basis is treated in either of two ways—(*a*) actual, (*b*) adjusted. The actual cost basis is reckoned on the acquisition cost or the actual cash cost including freight, carriage, and installation, but not including any discounts or other allowances. For strict accuracy the

TABLE II

TYPICAL RATES OF DEPRECIATION.

	Per cent.
Air compressors	4–7
Belting	7–15
Benches, steel	4
wood	7
Blower and fans	5–7
Blowpipes	10
Boilers	2–8
Buildings, brick	2
concrete	2
corrugated iron	10–15
steel frame	2–3
stone	2
wood frame	3–5
Cranes, jib	7
gantry	7
travelling	5
Electrical fittings—lighting	5
Electrical generators	3–7
Electric motors	3–10
Electrical testing equipment	7–10
Electrical switchboard—wiring	5–7
Electrical wiring, bare copper	2–3½
insulated copper	6
iron	6½
Electrical fuse-boards	9
Fences, wire	6
wood	10
Fire equipment	6–10
First aid and welfare equipment	5
Gas producers	7
Heating systems, radiators	4
plenum	7
steam	10

	Per cent.
Machine tools and small tools:	
Automatics, chucking	5
Screw machines	6½
Multi-spindle	7½–8½
Boring machines	6
Broaching machines	7
Chucks	15
Diecasting machines	7
Dies	22–50
Drills—all types	5–7
portable	15
Filing machines	7
Furnaces	5–7
Gauges	15
Hoists	5–9
Jigs	10
Lathes, all types	5–7
Machine foundations	10
Milling machines, all types	5–7
Patterns	20–25
Planers	6
Polishing machines	7
Presses, all types	5–6
Sand-blast equipment	10
Shapers	6
Motor trucks	15–25
Power-plant equipment	7½–10
Pulleys, shafting, hinges	3–8
Pumps	4–5½
Tanks, brick	3
concrete	2
steel	4
wood	5–9
Turbines, hydraulic	3–4
steam	5

adjusted cost may be used in which salvage value and cost of removal are deducted, so that the formula for depreciation basis may be:

$$\text{Depreciable amount} = \text{Actual cost} - (\text{salvage value} - \text{removal cost}).$$

CUSTOMER ____________			CONTRACT No. ____________		
PLANT ISSUED			PLANT RETURNED		
Date	Description	Value	Date	Description	Value

Fig. 27.—Card for revaluation of plant.

Where the cost of removal exceeds salvage value then the last factor will be positive and increase the depreciable amount. This basis is by far the most commonly used.

(2) *Cost and Maintenance Basis:* In this basis the depreciation is considered as covering the additional cost of repairs added to the actual cost. Thus the depreciation amount is represented by the following formula:

Depreciable amount = Actual cost − (salvage value − removal cost) plus estimated maintenance cost.

The chief objection to this basis is the difficulty of accurately estimating the maintenance cost.

(3) *Replacement or Reproduction Cost Basis:* This basis is estimated upon the cost of replacing or reproducing the plant or machinery on the basis of the current price, thus tending to achieve the aim of depreciation which is to provide for the replacement of the unit when it is worn out, obsolete, or scrap. This basis is becoming more commonly used, as it has the following advantages:

(i) More truly reflects cost of replacement.

(ii) Is more appropriate as a means of covering operating capacity from current assets.

(iii) Is the more correct means of covering depreciation costs for insurance, finance, etc.

Difficulties of this basis are:

(i) Continuous adjustment of values necessary to meet changes in market values.

(ii) Actual cost is more reliable than an estimate.

(4) *Existing Value Basis:* This method

				PRESSES Nos 175 184		
M/C No.	Make	Date of purchase	Cost	Description	Per ann.	Remarks

Fig. 28.—Typical page from machine and plant register.

Week ending................											Sheet No						Sheet No........			
Job No.... Description																				
Regn No	Clock No	Amount	Regn No	Clock No	Amount	Regn No	Clock No	Amount	Regn No	Clock No	Amount	Regn No	Clock No	Amount	Regn No	Clock No	Amount	Regn No	Clock No	Amount

Fig. 29.—Material abstract.

takes account of the market value of the actual plant or machinery upon which depreciation is to be made.

Methods of Apportioning Depreciation.—Several methods of computing and apportioning the amount of depreciation over the estimated life of the plant or machinery are in use. The chief of these are:

Cost summary					Contract No......		
Customer........................							
LABOUR					MATERIAL		
Date	Clock No.	Hrs.	Rate	Amount	Date	Regn No.	Amount
				Sheet No..... of..... sheets			

Fig. 30.—Cost summary card.

(1) Straight-line method.
(2) Annuity method.
(3) Reducing balance method.
(4) Sinking fund method.
(5) Production method.
(6) Revaluation method.
(7) Machine-hour method.

(1) *The Straight-line Method:* This is the simplest method and because of this is the one most commonly used. The life of the machine is estimated, also its value when salvaged or scrapped (called residual value), the number of years of life divided into the difference between its actual value and its residual, thus determining the value to be deducted annually. The formula is given below, where

n = Number of years in life of machine.
d = Depreciation amount.
V = Actual value.
S = Salvage value.

$$d = \frac{V - S}{n}.$$

If additions in capital value are made to the machine after its installation, then this amount must be added to the remaining value of the machine and a new value for the depreciation amount calculated on the basis of the remaining life.

Week ending............																	Sheet No.......			
Job No........ Description																				
Clock No	Hrs.	Amount	Clock No	Hrs.	Amount	Clock No	Hrs	Amount	Clock No	Hrs	Amount	Clock No.	Hrs	Amount	Clock No	Hrs	Amount	Clock No	Hrs	Amount

Fig. 31.—Wages abstract.

(2) *The Annuity Method:* Is based upon the consideration that interest is earned upon the amount of the diminishing value of the asset and that depreciation should bear its own earnings in this respect. The method is more properly applied to leasehold buildings, etc. A fixed annual sum is used as the depreciation amount and the interest on this is charged. The formula for the estimation of the rate of depreciation is given below—where:

Name											Contract No		
		DEBITS						CREDITS					
Date	Ref	Mat'l	Plant loaned	Hrs.	Wages	Expenses	Total	Mat'l	Plant returned	Total	Over head	Total to date	

Fig. 32.—Contract cost ledger.

d = Depreciation amount.
V = Actual value.
S = Salvage value.
n = Number of years in life of plant.
r = Rate of interest, plus 1.

$$d = \frac{(V\ rn - S)\ (r - 1)}{r - 1}.$$

The chief objections to this method are the intricacy of the formula and difficulty in estimating the true value of the asset at any period before the end of its estimated life.

(3) *The Reducing Balance Method:* By this method a constant-percentage rate of depreciation is deducted from reducing balance of the machine value, the rate being such that at the end of its life the value is reduced to the salvage value. A constant percentage is charged, beginning with the original cost and reducing this to the salvage value. This is a very fair method, but has as an objection—the placing of a heavy burden on the earlier period of the machine's life, leaving an almost negligible amount in the later years. This is offset by the fact that the amount to be spent on maintenance and repairs is certain to be heavier. The formula for finding the annual rate to be used to reduce the value to the salvage value is as follows:

$$d = 1 - \sqrt[n]{\frac{S}{V}}$$

where d, n, S and V are as above.

(4) *The Sinking Fund Method:* This uses a fixed sum per machine annually to be set aside and charged as an expense, the total of such sums for the whole plant being used as a premium for investment either in securities or endowment insurance. Alternatively, the amount may be credited to a sinking fund for re-investment in the business.

(5) *The Production Method:* This attempts to relate fluctuating volumes of output to costs. It is not to be recommended, because it requires varying rates and amounts of depreciation which are difficult to calculate. The aim is to charge a higher amount of depreciation during busy periods than during the slacker ones. The volume of output being, at best, an estimate, no certain basis is likely to be found. Other methods of arriving at the rates are operating hours and sales volume. The former is simpler and more reliable, whilst the latter is, again, an estimate.

Name							Contract No	
Date	Ref	Bricklayer	Plumber	Joiner	Painter	Electrician	Paviour	Total to date
		Hr	Hr	Hr	Hr	Hr	Hr	Hr

Fig. 33.—Wages cost book.

(6) *The Revaluation Method:* Is often used by

contractors and others, where plant is charged to the contract upon which it is used at a book value and revalued and credited when the contract is completed, the contract thus bearing the charge. Fig. 27 shows the method used in making the separate tool account for the contract and revaluing on return to the stores.

(7) *The Machine-hour Method:* In this method the probable life of the machine when in use is estimated and a rate per hour is given which will reduce the actual value to the salvage value. Thus, for each hour that the machine was in use a machine-hour rate is charged to the cost of the job to cover depreciation. The difficulty in this method is to know how many hours are involved in wearing out the machine, but this is actually no more difficult than the estimate for the life of the machine in years. Both have to depend upon experience and records.

Plant and Machinery Register.—It is essential for the purposes of estimating the depreciation chargeable that a plant and machine register should exist. This may be in the form of a ledger in book or card form. Fig. 28 shows a card for a machine from such a register, giving full particulars of the machine, its date of

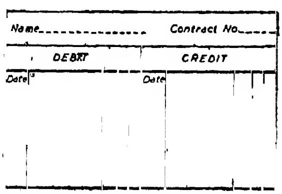


Fig. 34.—Material cost book.

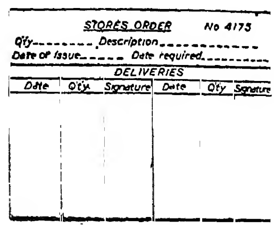


Fig. 35.—Stores order.

purchase, original cost, cost of installation, total cost, rate of depreciation, and amount of depreciation.

Methods of Apportioning Overhead.—Various methods of apportioning overhead to the product exist, the following being the most important:

(1) Production centre.
(2) Percentage on direct cost.
(3) Percentage on direct labour cost method.
(4) Man-hour rate.
(5) Machine-hour rate.
(6) Departmental rate.
(7) Percentage on direct material cost method.
(8) Rate per unit produced.
(9) Class of product.

Definition of and Calculation for Rate of Overhead for Each Method

(1) *Production Centre:* This is defined as "A convenient unit for the computation of costs made up of homogeneous machines or services within a factory." Types of centres are:

(*a*) Those items of equipment which have approximately the same capacity and will do relatively the same work. Examples: Automatic screw machines, diecasting machines.

(*b*) Equipment grouped together for the sole purpose of making a given product or process.

(*c*) Departments engaged upon the production of similar products of relatively equal value, using equipment of similar types for performing similar operations. Examples: Tool shop, die-making shop, core-making shop.

For the purpose of arriving at correct overhead figure, data have to be obtained for its calculation, viz.:

Shop area, power consumption, indirect expenses, salaries, depreciation, etc. These data are used to calculate relative amount of overhead which is absorbed

by the centre. Fixed charges are based upon the relative area of the centre to that of the factory as a whole. Power consumption is obtained either relatively by calculation of machine horse-power, floor area, or directly by installation of suitable meters. Indirect expenses are obtained by careful allocation of the charges incurred, and other charges, depreciation, etc., by relative floor area as above.

$$\text{Rate of overhead} = \frac{\text{Total expense of department}}{\text{Number of units, machine-hours, man-hours or value of units produced.}}$$

In a factory making a number of different products simultaneously on various groups of machines this is a fair and safe way of apportioning overhead.

(2) *Percentage on Direct Costs:* In this method the total overhead cost is expressed as a percentage of the actual or calculated cost, and this percentage applied to each job. This method must be inaccurate, as it presupposes that each

RUNNING WORKS ORDER No ________ W/E ________
TO MAKE ________ P No ________
OPERATIONS ________ Nos ________
DRAW MATERIAL FROM ________
PASS FINISHED WORK TO ________

	RECIEVED			OUTPUT						
	Issued	Received	Quantity	Quantity	Reject	Pay	Coy's scrap	Pass	Viewer	Received by stores
Thurs										
Fri										
Sat										
Mon										
Tues										
Wed.										
	TOTALS									

ADD CLOSING STOCK
ADD SCRAP
TOTAL DEALT WITH
LESS OPENING STOCK
TOTAL

TIME ALLOWED ________
TIME SPENT ________
COST % ____ WAGES COST ________
EMPLOYED ON JOB ________

Fig. 36.—Order form for complete assemblies, detailing components.

job uses labour and material of equal value. It takes no cognisance of the fact that labour and material of different rates and machines and equipment of different sizes and capacities are used in different jobs. It is, however, simple, and can be quickly and easily calculated.

$$\text{Rate of overhead (per cent.)} = \frac{\text{Total overhead costs} \times 100}{\text{Total direct labour and material costs}}.$$

(3) *Percentage on Direct Labour Cost:* In this method the total expense is expressed as a percentage of the total direct labour cost. It is a very simple method, very practical and accurate where there is not a wide difference in the types of processes and the labour costs. The disadvantages are that expense, labour, or machines incurred are thus not fairly charged, and where the products vary in cost a low rate of profit on some may be concealed.

$$\text{Rate of overhead (per cent.)} = \frac{\text{Total overhead costs} \times 100}{\text{Total direct labour costs}}.$$

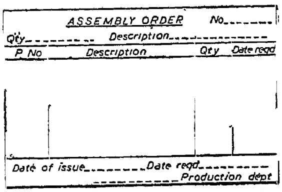


Fig. 37.—Assembly order.

(4) *Man-hour Rate or Direct Labour-hour Rate:* This is based on the presumption that time is the one intangible factor in the cost. It expresses the rate per direct labour-hour, which is obtained by dividing the total expenses for a given period by the number of productive labour-hours worked for that period. This is a very accurate and simply applied method, provided the rate is fixed for a given production group or centre. It should, however, be used with the machine-hour rate (No. 5 below), where expensive plant is used. Accurate records of the total productive hour must be kept, but this is a simple matter where a good system of time booking exists.

$$\text{Rate of overhead per hour} = \frac{\text{Total overhead costs}}{\text{Total productive hours worked}}.$$

(5) *Machine-hour Rate:* This can be used in any of the following ways:

(*a*) A simple rate per hour for the use of the machine and its attendant direct labour.

(*b*) A rate per hour for the machine with the direct labour charged separately.

(*c*) An additional rate for use with other rates.

This method of apportioning overhead gives greatest accuracy where production is entirely by machine. However, considerable work is necessary in collection of records of machine output capacities, but once these are available it can be certain that rates so obtained will be reliable. Where much plant exists of similar types, it is usual to group machines in types, a rate being set for each type. The calculation of the rate is intricate and requires the following data:

(*a*) Cost of floor space occupied (including working space) relative to general overhead.

(*b*) Expense of operating the machine including depreciation, interest on capital cost, insurance, power, maintenance, repairs, idle time, etc.

Further problems which arise with this method are (*a*) the recovery of idle time where this is serious; (*b*) variation in the number of operators working the machine; (*c*) variation of the number of machines in a group worked by a given number of operators; (*d*) the possibility of grouping machines of different types.

In regard to (*a*) where idle time is of considerable occurrence, possibility of increasing rate or of completely writing off cost should be considered.

(*b*) The use of the leading operator's time-bookings on the job should serve as a means of booking machine's productive time.

(*c*) This is overcome by allocating a standard minimum number of machines to be operated by one operator.

(*d*) Where machines are of relatively similar costs, these can be grouped

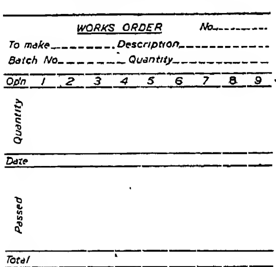


Fig. 38.—Works order for repetitive work.

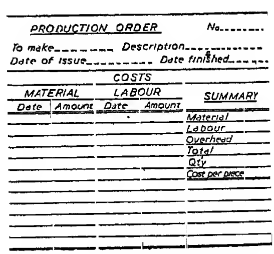


Fig. 39.—Combined order and cost summary.

PART No ______________ JOB No ______________

Opn No	Opr No	Quan	Time	Rate	Cost	Opn No	Opr No	Quan	Time	Rate	Cost	Opn No	Opr No	Quan	Time	Rate	Cost	Opn No	Opr No	Quan	Time	Rate	Cost

MATERIAL						SUMMARY
Quan	Description	@				

Fig. 40.—Cost summary card.

together even though of different types. Their relative productive capacity, however, should also be similar.

$$\text{Rate of overhead per machine-hour} = \frac{\text{Total overhead cost of operating and maintaining machine or class of machines}}{\text{Number of machine hours}}.$$

(6) *Departmental Rate:* This is expressed as a percentage of labour cost or a fixed rate per direct labour hour. It is similar to the production centre method, which it predates. Its chief merit is that it takes account of the differences in costs of operating departments.

$$\text{Rate of overhead based on direct labour cost or rate per hour} = \frac{\text{Total overhead expense for department}}{\text{Total direct labour cost or total direct labour) hours}}.$$

(7) *Percentage on Direct Material Cost Method:* This method is applied where a homogeneous raw material is used, such as metal ores, rubber, chemicals, etc. In many industries where these materials are processed into a variety of forms, the cost is used on the unit fabricated. The apportionment of the overhead expense on the basis of the raw material used forms a suitable means.

$$\text{Rate per unit of raw material used} = \frac{\text{Total overhead expense}}{\text{Total units of raw material}}.$$

This method is not satisfactory in any other than the uses given above. It should not be used for machining of parts of dissimilar types.

(8) *Rate per Unit Produced:* Where parts are of uniformity in size, type, or direct labour time or cost, or where produced in homogeneous form and marketed by some measurement or capacity, the overhead expense can be expressed on a basis of these units. One advantage of this method is that it gives a standardised rate of overhead cost for all the output.

$$\text{Rate of overhead per sack, lb., feet, box, barrel, gallon, etc.} = \frac{\text{Total overhead expenses}}{\text{Number of units (sacks, lb., feet, etc. produced)}}.$$

(9) *Class of Rate:* Where various forms of goods are produced from the same material—say, brass rods, brass forgings, brass castings or steel beams, rails, and other sections—greater expenses are involved in some types than others,

A method of apportioning the overhead expense is therefore to rate the overhead on the basis of expenses involved and the output made.

$$\text{Rate per unit of product for a given class} = \frac{\text{Total overhead expense for the class}}{\text{Total output produced in units}}.$$

Application of the Costing Methods

(1) Job Costing

Contracts : Procedure

(1) *Contract Number :* Each contract or order is given a number by which it is referred to in all the books and forms.

(2) *Material :* All material drawn from the stores for use on the contract is issued against a requisition which must bear the contract number. Where material is purchased outside for a particular order, the contract number must be used to identify it. Excess material returned to stores must likewise bear the contract number on the stores debit note.

COST SUMMARY FOR TYPE.....CARBURETTER

P No	Description	No off	Cost each Lab'r Time	Cost each Mat'l	Cost per set Lab'r Time	Cost per set Mat'l
		Assembly cost				
		Total cost				
Made out by		Checked by		Date		
Drawing No		Summary made out				

Fig. 41.—Cost summary for assembly.

(3) *Material Abstract :* It is sometimes useful to use a Material Abstract (Fig. 29) on which is summarised weekly the cost of the material issued on all contracts worked on. This ensures that the material issued is covered.

(4) *Cost Card* for the contract (Fig. 30) forms a ready means of summarising for each contract the cost of the material issued. The cost is entered from the requisition or material abstract.

(5) *Labour :* The time spent on each contract is calculated from the time sheets (Fig. 17), job tickets (Fig. 19), time analysis (Fig. 18), or whatever system exists. Full particulars of the cost of each appears in the Wages Book.

(6) *Wages Abstract :* Supplementary to the Material Abstract we have the Wages Abstract (Fig. 31), which summarises weekly the wages paid for the work on the contract in hand. In the building and other allied trades, the Wages Abstract will be in sections according to the types of labour employed, pavior, joiner, stonemason, plumber, etc.

(7) *Cost Card* for the contract (Fig. 30) has provision for the entry direct from the time sheet, job ticket, time analysis, or wages abstract for each entry.

Contract Cost Ledger.—Another method is by the use of a Contract Cost Ledger (Fig. 32), in which an account of all expenses connected with the contract can be entered.

It can be in loose-leaf form providing rulings to cover each type of expense. As an adjunct to this ledger the Wages Cost Book (Fig. 33) and Material Cost Book (Fig. 34) form means of expanding these prime costs. These costs are posted up as convenient from the time sheets, wages book, etc., and from the material abstract or requisition.

UNIT COST FOR........................ DRG. No..........

Batch No	Cross Qty	Rejects	Nett	Material Cost	Labour Hrs. Amount	Overhead	Total Cost	Cost Per Unit	Date

Fig. 42.—Cost sheet for unit costing.

Factory Job Costing

(1) *A Works Order* is issued for each job, a

RAW GRINDING ACCOUNT										APRIL 1944			
AMT TONS	MATERIAL				HRS	LABOUR				SERVICES			
3000	Raw material No 2	400	0	0	1500	Crushing	125	0	0	Power	75	0	0
					608	Grinding	50	0	0	Light	35	0	0
2000	Raw material No 3	125	0	0	710	Drying	55	0	0	Heat	52	0	0
					350	Mixing	27	0	0	Water	16	0	0
					200	Maintenance	15	0	0	Fuel	12	0	0
					370	Labouring	22	0	0				
					—	Clerical wk	29	0	0				
5000		525	0	0	3788		303	0	0		190	0	0

CLINKER GRINDING										APRIL 1944			
AMT TONS	MATERIAL				HRS	LABOUR				SERVICES			
1500	Gypsum	1300	0	0	1100	Grinding	84	0	0	Power	34	0	0
					175	Maintenance	12	0	0	Light	19	0	0
					307	Labouring	18	0	0	Heat	27	0	0
					—	Clerical	31	0	0	Water	19	0	0
										Fuel	11	0	0
		1300	0	0			145	0	0		114	0	0

Fig. 43.—Accounts for manufacture of cement.

separate number given to each works order, and some means of collecting the cost against each order is devised.

(2) *Type of Work:* The works order form will vary with the kind of work undertaken as

(*a*) Component work in which parts are made for assemblies.

(*b*) Repetition work in which the parts are made in repetitive batches.

(*c*) Small order work in which the numbers are not large and the routing of the work is simple.

(3) *Orders for Component Work:* These may take one of several types, such as:

(*a*) Stores order to produce when stocks reach minimum (Fig. 35).

(*b*) Repetitive batches ordered on some type of Standing Order (Fig. 36).

(*c*) Orders for complete assemblies detailing components (Fig. 37).

In each of these cases the costs of the components are determined and the cost of the assembly ascertained by a summary of costs of the components used, plus the assembly cost.

(4) *Repetition work* will require to have the work broken down into suitable batches, both to aid handling in the factory and enable close check on costs. The form of order will be similar to Fig. 38 as used above.

(5) *Small order work* will invariably involve quite small amounts of labour and material, and a suitable type of combined order form and cost summary is shown in Fig. 39.

(6) *Operation Layouts* will be necessary for use with the types of work given in 2 (*a*) and (*b*) above. A typical Operation Layout is given in Fig. 22 (page 971, Production Control Section).

(7) *Collecting Labour and Material Costs:* For the purpose of collecting labour and material costs some form of Cost Summary Card is necessary (Fig. 40), on which is collected the individual items of cost involved.

(8) *Labour Costs:* These are collected on to the Cost Summary Card by entering the cost of the time spent from the time sheets (Fig. 17), time analysis (Fig. 18), or job cards (Fig. 19).

(9) *Material Costs* are collected from the requisitions passed for each job. Requisitions for direct material must bear the job number for the work.

(10) *Time Studies* should be taken to ensure that time spent is not excessive.

(11) *Piecework or Bonus Schemes* should be applied.

(12) *Assembly Costs* for standard products are made by placing cost against each item on a Cost Schedule for the product (Fig. 41). Pro-

PRODUCTION COST FOR .... TONS CEMENT 1944							
Qty	Operations	Material	Labour	Services	Overhead	Total	Unit cost
	Bro for last month						
	Total						
	Carr for						

Fig. 44.—Cost summary for process cost.

COST SUMMARY	Opn. No	1	2	3	4	5	6	7	8	9	10	Total of Carr. for.
In procession	194											
Issued this month												
Material cost												
Labour cost												
Completed												
Rejected												
Good												
In procession	194											
Cost per Unit—												
Running totals—												
Quantity good												
Labour cost.												
Material cost												
Overhead cost												
Cost per unit												
Assembly cost												
Production cost												
	Made out by				Checked			Date		Cost summary No		

Fig. 45.—Cost summary for operation costing.

vision is made for adding in the assembly cost, the total direct cost being obtained by addition (see also "Composite Costing").

(2) Unit Costing

This system is applied where production is continuous of parts or material which are almost completely identical in form. Such parts are sweets, cakes, and pharmaceutical products. In this type of production it is difficult to distinguish the batches, as many parts of the process are likely to be proceeding at the same time, and the segregation of waste and scrap from each batch will probably be impossible. It is quite possible to apply this system to the costing of component parts of an assembly.

The type of cost sheet used for this system is shown in Fig. 42 and will be found self-explanatory.

(3) Process Costs

In this system the process is continuous with distinct operations, but they occur simultaneously. The material or the products are not distinguishable until the finished product. There is no need to cost separate batches, but only to obtain the cost of the finished product by the collection of the costs of the labour and material employed and the relation thereto of the quantity of finished work.

Procedure :

(1) Accounts are made for each process or operation involved and the labour, material, and expenses ascertained.

(2) The quantity produced by each process or operation is passed to the next operation, whilst any by-products made are credited to the operation making them.

(3) The by-products, if further treated for making into a finished product, are treated in the same manner as above.

(4) Opening and closing stocks are likely at the end of each period, so that account must be taken of their values and the necessary debits and credits.

Fig. 43 shows such a series of accounts made for the costing of cement, and Fig. 44 shows the summary necessary to arrive at the unit cost of the product.

OMNIBUS RECORD CARD									No.______	
Bus No.________									Date No.______	
Route No.________									Booked out______	
Driver No.________									Booked in______	
Conductor No.________									Engaged...Hr...Min	
Distance of route________Miles									Total____Miles	
Trip No	Fares collected 1	2	3	4	5	6	7	8	No carried	Value
Total										

TIME BOOKINGS	SUPPLIES USED
Driver	
Conductor	
Mechanics	
Cleaners etc	
Total	Total
Remarks	

Fig. 46.—Record card for operating costs.

WEEKLY RUNNING COST OMNIBUS No........ Week ending........			
OPERATING COSTS			
Labour cost		Hr's	
Supplies			
Total		Hrs	
MAINTENANCE COST			
Repairs	Labour	Hr's	
	Spares		
Garage	Labour	Hr's	
Tyres			
Total		Hrs	
FIXED CHARGES			
Insurance			
Depreciation			
Interest			
Tax			
Garage	Rent		
	Rates		
	Taxes		
	Fuel		
	Power		
	Light		
		Total	

Fig. 47.—Running cost card for operating costs.

The figures given are illustrative only and are not necessarily correct.

TOTAL OPERATING COSTS		FOR MONTH 19
OPERATING	MAINTENANCE	FIXED
No Vehicles	Repairs	Insurance
Total mileage	Labour Hrs	Depreciation
Total passenger	Spares	Interest
Labour	Garage	Tax
Drivers Hr	Labour Hrs	Rent
Conductors Hr	Tyres	Rates
Mechanics Hr	Other expenses	Taxes
Cleaners Hr		Fuel
Miscellaneous Hr		Power
Total Hr		Light
Supplies		
Total	Total	Total
Days working		
Days idle		
Cost per mile		
Cost per day		
Total	Per mile	Per day
Operating		
Maintenance		
Fixed		
Total		

Fig. 48.—Operating cost summary.

(4) Composite Costing

This system is usually applied to finding the finished cost of an assembly, the component parts of which have been costed by one of the other systems. The completed assembly is costed by totalling the costs of all the components and adding the cost of the assembly. The illustration under Factory Job Costing (Fig. 41) shows how this is applied. This system is commonly used in the manufacture of motor-cars, machine tools, radio sets, and all other products where there is a multiplicity of components.

(5) Operation Costing

This is an application of process costing to the costing of components and assemblies made on a continuous-production basis. The form of cost summary necessary for this system is shown in Fig. 45. Each component made is costed by this method, the assembly operation treated in the same way, and the final assembly costed by a cost summary similar to Fig. 41.

(6) Operating Costs

This is applied to the determination of the cost of operating public utilities, such as omnibuses, tramways, railways, electricity supply, etc. By its use the cost of the basis on which charges are made, such as per mile, per ton, per kilowatt-hour, is found. We give as an illustration the forms necessary for operating an omnibus service, and show how the charge per mile is determined (Figs. 46–48).

(7) Standard Costs

The cost systems enumerated above all suffer from the defect that a time-lag is inevitable between carrying out the work and the determination of the cost. Furthermore, the only means they provide of checking the efficiency of working is by the comparison of one batch of work against another. Again, the costs of operating the systems can be very high. The lack of any form of standard cost for comparing the costs of batches or the means of checking inefficiencies and the mass of detail which was collected without any real benefit, led to the evolution of the system of standard costs.

MATERIAL COST RECORD CARD					
Material	Brass rod to BSS 249				
Date	P No	Description	per cwt	per lb	Sig
5-1-44	B3	3/16 Dia	72/4	7·75D	A S
7-2-44	B9	9/16 Dia	75/-	8·04D	A S
Sheet 1 of		Sheets		Symbol B	

Fig. 49.—Material cost record card.

Definition:

Standard Costs: Are those determined by computing manufacturing specifications of labour, material, and overhead to given standards.

Standard Cost System: Is that which compares actual trading results with those predicted by the computation of standard costs.

Deficiencies Emphasised: From the above definitions it is obvious that the deficiencies which occur in departing from normal working can be easily ascertained. To this end the standards are set, based on labour, material, and overhead.

EXPENSE SUMMARY FOR M DEPT — MONTH JUNE 1941

Symbol	Expense	Hours % capacity 50	60	70	80	90	100	Rate/Hr.	Monthly expense 50%	60%	70%	80%	90%	100%
M.7.	Supervision	168	168	168	336	336	336	7/2	60/-/-	60/-/-	60/-/-	120/-/-	120/-/-	120/-/-
M.9.	Clerical labour	336	336	336	336	336	336	1/10	30/10/-	30/10/-	30/10/-	30/10/-	30/10/-	30/10/-
M.12.	Mis-labour	1344	1344	1344	1680	1680	2688	2/1	234/2/-	234/2/-	234/2/-			
M.4.	Repairs	471	471	471	626	626	626	2/9						
M.6.	Maintenance	316	316	316	672	672	672	2/9						
M.17	Supplies													
M.20	Mis-expences													
M.31.	Machine cost													
											etc			
M.1	General expenses													
M.2	Rent, rates, taxes													
M.3	Power													
M.4.	Fuel cost													
	Total													
	Productive hours / Overhead rate				176%				9350	10280	11215	12150	13085	14020

Fig. 50.—Departmental expense sheet.

Advantages of the System

(1) Actual performance easily compared with model standards, readily showing profit or loss.

(2) Variations apparent in details, showing where deficiencies have occurred.

(3) Cost variations in labour, material, or expenses, made apparent at early stage.

(4) Market fluctuations affecting gains or losses readily revealed.

(5) Management able to judge of departmental economy in working with satisfactory output.

(6) Ability to judge possibility of price adjustments.

(7) Usually more simple cost method with less labour employed.

Setting Standards

Labour standards are based upon:

(1) Standard operation layouts for each component or job.

(2) Standard labour rates for each operation.

(3) Standard times for each operation based upon results of time study.

(4) Schedule of rates for use by cost department.

Material standards are based upon:

(1) Specification of material as to quality.

(2) Specification of material as to quantity per component or number of components based on known standards of scrap and waste.

(3) Standard price having regard to current rates.

(4) Standard price per component or number of components based upon specification of quantity and current rate.

STANDARD COST for................P No.....

LABOUR

Opn No	Description	Time	Rate	Cost

MATERIAL

P No	Description	Q'ty	Rate	Cost

SUMMARY

	Cost %	Cost each
Labour		
Material		
Overhead		
Total		

Made out Date P No

Fig. 51.—Standard cost for unit.

STANDARD COST FOR TYPE ASSEMBLY

Made out..........Date.........P No.....

COMPONENTS

P No	Description	No-off	Total cost

ASSEMBLY

Labour

Overhead

Total assembly cost

Total cost

Fig. 52.—Standard cost for assembly.

(5) Schedule of current prices for use by Cost Department.

Overhead standards are based upon :

(1) Budgeted expenses at standard rates for normal productivity for department, machine, or type of labour.

(2) Rate or percentage based upon above.

(3) The rate is based on machine-hour, direct labour-hour, or a percentage of labour, material, or total prime cost.

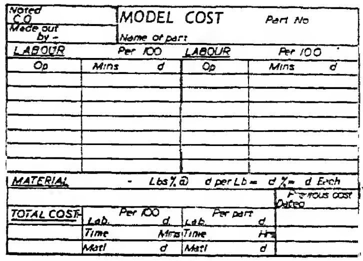


Fig. 53.—Model cost card (component).

Labour Standards

Each component is provided with a suitable operation layout which gives the standardised method of making it. The labour for use on each operation is standardised as to type and rate. By the use of time-study definite scientifically established base-times can be determined, and with the use of wage incentive plans the labour cost standard set (see Production Control, page 960, Fig. 22, for typical operation layout, and Wage Incentive Plans, pages 1060 to 1063).

Material Standards

Each component is specified as to material quality to be used by the Designs Department and definite standards of quantity allowance for each is determined by past experience. Allowances of waste and scrap are well-established data in most organisations. The degree of fluctuation which occurs on most material used in the light engineering industry is very small. However, a price record for each type of material, specified as to form, etc., should be available to record any such fluctuations (Fig. 49). Standardisation of material forms and qualities is an important step, apart from the economy of storage, etc., as this enables the fluctuations to be more easily controlled. Contract prices for materials are useful also in this respect.

Overhead Standards

Each department or machine or production centre has its expense schedule, giving current expenses on a quarterly, semi-annual, or annual basis. Such a budget can be compiled from the weekly wages analysis sheets (Fig. 25) and from the expense journals based on the allocated expense for the department, machine, or production centre. Fig. 50 shows such an expense schedule or budget.

Standard Costs for Parts

The established standards for labour, material, and overhead enable the standard cost for the parts and, by building on an assembly schedule, the cost of an assembled product to be determined. The forms for such parts or assembly are shown in Figs. 51 and 52.

Normal Capacity

Established standards for all the cost factors are based on the efficient use of the plant at its normal capacity. Allowance must be made for any possibility of unemployed capacity if the business is not fully established and its plant idle for any portion of the trading period. Fig. 50 shows under the various columns the effect of fixed and variable charges for various capacities.

One of the chief benefits of the standard cost system is the possibility of establishing budgetary control whereby a financial programme for a given production unit can be promulgated.

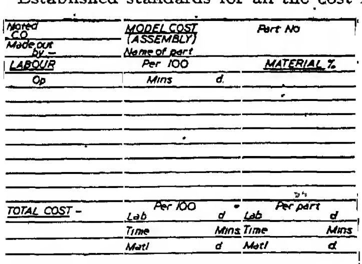


Fig. 54.—Model cost card (assembly).

WAGE INCENTIVE PLANS

Definitions

Incentive.—An influence which will induce increased effort above a standard.

Incentive Plan.—A means of establishing a method and standard which will give employer and employee benefit from performing the task set.

Task.—A set basis which the incentive plan uses as its standard.

High Task.—Is set after steps have been taken to effect proper standardisation of the method to give maximum efficiency. In this form of task time study or time and motion study have been used and the tools, etc., have been introduced to effect maximum productivity.

Low Task.—The methods have not been necessarily investigated, but task is set upon standards found by past experience or recorded results.

Essential Principles governing an effective incentive plan are:

(1) Reward to employee should be commensurate with effort made.

(2) Reward should be substantially above basic wage to make effort worth while.

(3) Plan should be easily understood by employee.

(4) Employee should be able to check results over a fairly short period.

(5) Reward and effort should be directly related and the relation easily understood.

(6) Quality must be safeguarded.

(7) Employee should have some representation in the working of the plan.

(8) Guarantees should be made that conditions under plan will not worsen the employee's position economically.

(9) Material and parts worked upon should be up to specific standard.

General Divisions of Plans

(1) Day rate.
(2) Efficiency upgrading.
(3) Piecework.
(4) Premium plans.
(5) Task and bonus plans.
(6) Group bonus plans.
(7) Sharing plans.

(1) **Day Rate.**—Payment at given rate for a specific length of working time.

(2) **Efficiency Upgrading.**—In these plans employee is induced to give of his best by recording outputs, and making payment on a high basis for the best performance, with sliding scale, down to untrained labour, for other grades.

(3) **Piecework.**—Payment on a basis of amount of good work done, either with or without a guaranteed day rate.

(4) **Premium Plans.**—Are based upon past records of output and the time saved over the task set is shared on some prearranged basis by employer and employee. They are usually " Low task plans."

(5) **Task and Bonus Plans.**—Are similar to above except that task is set upon the application of the best methods after the job has been standardised by time and motion study. They are generally " High task plans."

(6) **Group Bonus Plans.**—Are those shared by a group of operators or a whole department. The task set may use any of the incentive plans mentioned above.

(7) **Sharing Plans.**—Are those, such as profit sharing or co-partnership, in which the payment is based upon the periodical earnings of the organisation.

Classes of Incentives

Class I: Employer takes all gains or losses.

Class II: Employee takes all gains or losses.

Class III: Gains shared between employer and employee with guaranteed day wage.

Chief Plans with most Important Characteristics

CLASS I

Day Rate.—Based on rate per hour, day, week, or other specified period. Not a true incentive plan.

Multiple Time Rate.—Based on recorded outputs with graduated steps for various grades of work or efficiency.

CLASS II

High Piecework.—Payment based upon output with a high task fixed by time and motion study and job standardisation with or without a guaranteed day rate.

Taylor.—A multiple piece-rate plan.

Merrick.—A multiple piece-rate plan, an improvement on above, with two rates, one for basic performance and one between basic and high. Useful for training unskilled labour.

Gantt.—Combines time rate and high piece rate with a 20 per cent. step bonus between. Based on time saved. Gives bonuses to supervisory staff on basis of earnings made by operatives under its charge.

CLASS III

Halsey.—Two plans: (*a*) 50 : 50 with time guarantee; and (*b*) 40 : 60 without time guarantee.

Rowan.—Similar to above but improvement, as employer does not pay excessive rate over 200 per cent. high task.

Barth.—Improvement on above, giving good inducement to beginners and learners without risk to employer. Gives good payment within short time for easy jobs.

Bedaux Point Plan.—Similar to Halsey 50 : 50, except that employee's 50 is replaced by 75 and high task. Remaining 25 per cent. goes to supervision and all who contribute to production, as bonus. Places special stress on value of good control and gives bonus to so-called non-productive labour.

Various Plans Analysed

Formulæ used for showing basis of compiling earnings use the following symbols:

Np = Number of parts made.
Rp = Rate per part paid.
Rh = Hourly rate.
Hd = Hours per shift.
Ha = Hours actually worked.
Hs = Hours set as standard for Np.
B = Bonus per cent.
E = Actual earnings per hour.

TABLE OF WAGE INCENTIVE PLANS

Plan	*Formulæ for Earnings*	*Where Used*	*Characteristics*
(Class I) Day Rate	E = Ha × Rh	For work where standards have not been devised.	Simple. Clerical work minimum. Is not an incentive.
Multiple Time Rate	E = B × Ha × Rh	For upgrading employees who reach given standards. A low or high task plan.	Simple. Records must be made of passed production. Needs care and attention.

Plan	*Formulæ for Earnings*	*Where Used*	*Characteristics*
(Class II) High Piecework	E = B × Hs × Rh ; or Np × Rp	For repetition work with high task.	Simplest and yields best results but requires control at high outputs.
Taylor Differential Piece Rate	E = Np × Rp (1) = No. of pieces × low rate E = Np × Rp (2) = No. of pieces × high rate.	For upgrading efficient worker, in two stages.	Now discarded in favour of Merrick and Gantt Plans.
Merrick Multiple Piece Rate	Up to 83 per cent. high task : E = 1 × Hs × Rh Between 83 and 100 per cent. of high task : E = 1·08 × Hs × Rh Above 100 per cent. high task : E = 1·20 × Hs × Rh	For upgrading less efficient workers.	Is flexible and simple. Tables of earnings should be provided to clerks.
Gantt Task and Bonus Plan	Up to task : E = Ha × Rh = Day rate At and above task : E = 1·20 Hs × Rh	For jobs where delays due to machine are likely.	A combination of day rate and high piecework. Gives guarantee of earnings to less efficient, but abuse likely and therefore should be watched.
(Class III) Halsey 50 : 50 Constant Sharing Plan (with guaranteed day rate)	Up to 62½ per cent. of high task : E = Ha × Rh (day rate). Above 62½ per cent. of high task : E = Hs Rh 0·5 (Hs − Ha) Rh (i.e. 50 per cent. of time saved is shared by worker and employer).	For beginners where no safe standards exist.	Gives guarantee of day rate to those unable to make standard time. Simple and just. If inaccurate, loss on either side is not great.
Halsey 40 : 60 Constant Sharing Plan (without guaranteed day rate) up to 70 per cent. of high task	Up to 70 per cent. of high task : $E = \frac{Rh}{35} \times 20$ Hs 21 Ha. At higher efficiencies High Piecework should be used.	For beginners.	For lower efficiencies gives higher earnings than under piecework though less than day rate. Simple and just.

TABLE OF WAGE INCENTIVE PLANS—*cont.*

Plan	*Formulæ for Earnings*	*Where Used*	*Characteristics*
Rowan . .	Up to low task: $E = Ha \times Rh$ = Timework At and above low task: $E = Ha\,Rh \left(\frac{Hs - Ha}{Hs}\right) \times Ha\,Rh$ = Time wages. Percentage of time saved × Time wages.	For jobs which are difficult to time study or ascertain accurate standards.	Gives good earnings above low task but not excessive at high productions. Not so simple as the Halsey Plans.
Barth . .	Up to $62\frac{1}{2}$ per cent. or 100 per cent. high task: $E = \sqrt{(Hs\,Ha)} \times Rh$ Above 100 per cent. high task use some other plan, as Gantt.	For beginners.	Gives good earnings for low efficiencies without any time-rate guarantee. Not simple to estimate, therefore clerks should be given tables.
Bedaux Point Plan	Up to 100 per cent. high task: $E = Ha \times Rh$ = Time wages. Above 100 per cent. high task: $E = Ha\ Rh\ 0{\cdot}75\ (Hs - Ha)\ Rh$ = Time wages × percentage of wages cost of savings.	For widely different types of work.	Used for non-standardised operations and "non-productive" work.

Group Incentives are used where operators work in groups of from two upwards. The essentials for the success of this form of incentive are:

(1) Work shall be of co-operative nature, implying interdependence of workers.
(2) Operators should work in close proximity.
(3) Operations shall be consecutive.
(4) Elimination of operators below standard.
(5) Suitable scheme for assessing individual contributions of operators.

Most Suitable Applications.—(1) Product allowing simultaneous work, e.g. aircraft, automobiles, ships, etc.

(2) Conveyor work.

(3) Product requiring wide range of skill among operators engaged, thus making assessment of individual effort difficult.

Wage Incentive Plans Used.—(1) Sharing plans (Halsey and Bedaux).
(2) Empirical plans.
(3) Two-time plans.
(4) Premium plans.

Compression Springs.—The compression spring comprises an open-coil spiral spring which is capable of resisting a compressive stress. Springs of this type find extensive industrial and other application. They are manufactured in numerous forms and from various types of wire, according to their purpose. Though it is essential in certain instances to employ square, rectangular, or special sectioned or shaped wire, most compression springs are manufactured from round wire. A typical compression spring is shown below (Fig. 1).

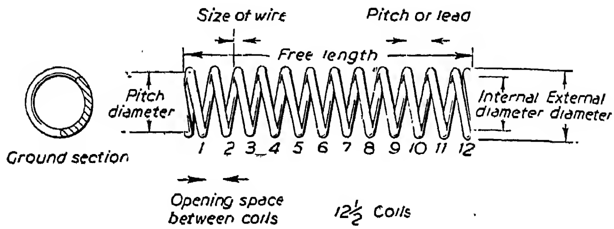


Fig. 1.—Principal dimensions of compression spring.

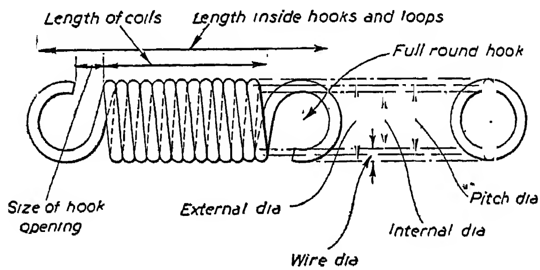


Fig. 2.—Principle dimensions of extension spring.

Extension Springs.—An extension spring may be described as a closely coiled spiral or helical spring, offering resistance to a pulling force. They are manufactured from round and square wire. The coils are generally close-wound and touching one another. Their difference from the compression spring is that whereas the coils of the latter are separated, and forced together only by the compression stress, the coils of the former are in contact, and wound so firmly together that a considerable effort is necessary to separate them. This load, built up by coiling, is termed initial tension and to some degree can be controlled. The illustration shows an extension spring and its dimensional features (Fig. 2).

The Basic Law in Spring Manufacture.—The basic law in spring manufacture and design is that first formulated by Hooke, who proved that stress divided by strain is a constant within the elastic limit of the material employed. Thus, if a steel rod is twisted 10 degrees by the application of a load, then a 20-degree twist would call for double that load. This, of course, ignores hardness or other physical properties of the steel. The basic formula for torsional stress can be obtained from most text-books on mechanics, and is : $S = \frac{MV}{J}$ for material

in torsion. In this formula, M is the moment of the force $\frac{D}{2} \times P$; V is the distance from fibre under consideration to centre of gravity—generally the external fibre. For wire, therefore, $\frac{d}{2}J$ is the polar moment of inertia: $\frac{3{\cdot}1416d^4}{32}$ for round sections.

Consideration of the stress to which a spring is subjected, and its working conditions, is highly necessary to intelligent spring design.

Calculations Affecting Design.—We now come to those calculations affecting the design of round-wire springs. When calculating stress, the above values are substituted and the expression is simplified, so that the formula now becomes:

$$S = \frac{P \times D \times 2{\cdot}55}{(\text{diameter of wire})} \text{ or } d^3.$$

Here, P equals load in pounds on the spring; D equals mean or pitch diameter, i.e. the external diameter of the spring less the wire dimension in inches; d is the wire diameter in inches, and S is the stress in pounds per square inch in torsion.

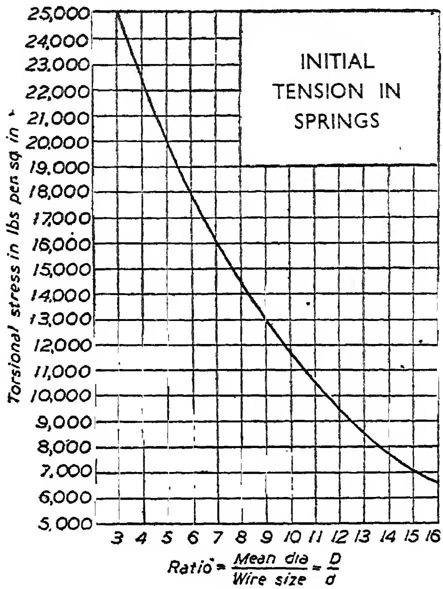


Fig. 3.—Initial tension in extension springs of oil-tempered wire or hard-drawn spring wire as coiled in an automatic coiler. Figures at left represent average maximum stress (without Wahl correction factor) for maximum load obtainable as initial tension, for various ratios of mean diameter (D) to wire size (d) shown below:

$$\text{P or load (in lb.)} = \frac{Sd^3}{2{\cdot}55D}.$$

The above is torsional stress only, and does not take into account total stress to which the wire is subjected as the ratio of wire dimension to mean spring diameter changes.

A formula to meet this case is as follows:

$$S \text{ max.} = \frac{\frac{16PR}{3{\cdot}1486d^3}\left(\frac{(4C-1)}{(4C-4)}\right) + \frac{0{\cdot}615}{C}}{Y}$$

Here R is mean radius in inches; d is wire diameter in inches; P is load in pounds; C is $\frac{2R}{D}$. By obtaining the numerical ratio of mean diameter to wire diameter it is possible to obtain a factor from a curve based on this formula, which is Y in the formula. Then total stress equals S × Y.

All calculations of important high-duty springs with a mean diameter ratio to wire size below eight should be made by this formula, which is applicable to both round and square wire.

Ascertaining Size of Spring.—The next requirement is a means of ascertaining the size of the spring. This is obtained by means of the following formula: $S = \frac{2{\cdot}55PD}{d^3}$. In this, S is the stress in pounds per square inch in torsion; P is the load in pounds on the springs; D the mean or pitch diameter; and d

the diameter of the wire in inches. Thus, if the stress is once known, the wire diameter cubed can be obtained, and by working out the formula the value of d, i.e. the wire size, is obtained.

It is then required to calculate the rate of the spring, which is done, once the wire size is known, by means of the formula : $F = \frac{8PD^3N}{Gd^4}$. In this formula, F is the deflection in inches ; P the load in pounds ; D the mean diameter of the spring; N the number of active coils; G the modulus of the material in torsion, i.e. 11,500,000 for steel; and d is the wire diameter in inches. If solid height is the decisive factor, certain substitutions will have to be made in this formula. As a rule, it is inadvisable to compress any spring in its working range to such an extent that the coils are in close contact. There should be a little space separating each coil when taking solid height into the reckoning.

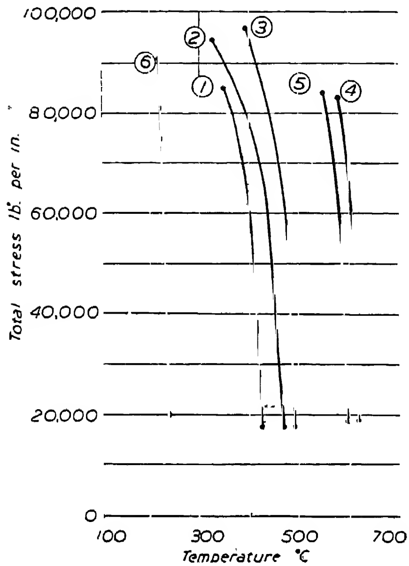


Fig. 4.—Allowable stresses in various spring materials at high temperature.

1. Monel metal. 2. Special valve-spring wire. 3. Chromium-vanadium steel. 4. Stainless steel (18/8). 5. Stainless steel (12–14 per cent. chromium). 6. Music wire. Loss in load is not more than 10 per cent.

Hardness of Material.—An important point to be observed is that the hardness of the material of which the spring is made makes no difference to the calculation of free length. In other words, springs made from a material having high elastic limit will be more extensively deflected in advance of attaining their elastic limit and therefore sustain a heavier load, because their rate per unit of deflection does not alter whether the material be hard or soft. As free length affects stress in design, it is possible to coil with a good deal of space between the coils, according to the solid stress and the elastic limit of the material. This space is regulated by the extent of set when solid compressed allowed for in coiling. The maximum load

	Steel Music Wire $<$ 0·015-*in. dia.*	*Steel Music Wire* $>$ 0·015-*in. dia.*	*Carbon-steel Wire*
	12,000,000	11,500,000	11,500,000
Lb. per sq. in.	*Chrome-vanadium Steel Wire*	*Hot-rolled Steel Rods* $>$ $\frac{1}{2}$-*in. dia.*	*Stainless-steel Hard-drawn Wire*
	11,500,000	10,500,000	10,500,000
	Monel Metal	*Phosphor Bronze*	*Brass* 66-34
	9,200,000	6,250,000	5,000,000

should not be over 62,000 lb. stress per sq. in., however, if satisfactory service is desired. Since the torsional modulus is an essential part of the deflection formula, and varies with the type of material of which the spring is made, it will be useful to give a brief table of values, based on the principal spring-making materials. This will be found in the table on p. 1066.

It will be observed that the hot-rolled rods have a lower modulus value than most of the other types of steel materials. This is because the effect of hot rolling is to form a soft or decarburised surface layer on the material. It must be remembered that the extent to which decarburisation of the surface has proceeded, i.e. the extent to which carbon content has been reduced, has an effect on the modulus value, so that the figure given in the table must not be regarded as universally applicable. It is merely an average value. If the rods are ground on the surface after rolling, in order to remove this soft skin, the modulus value will rise to a figure equivalent to that of the carbon and low-alloy steels as given in the table.

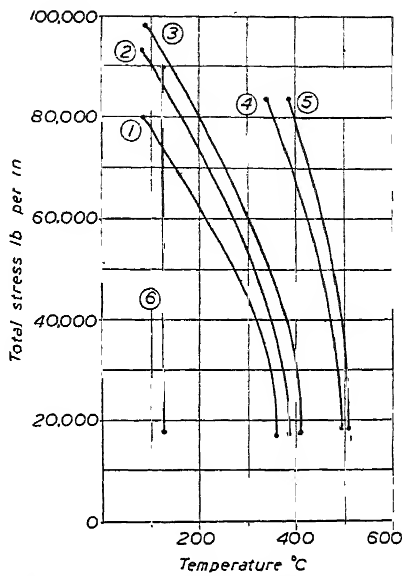


Fig. 5.—Allowable stresses in various spring materials at high temperature.

1. Monel metal. 2. Special valve-spring wire. 3. Chromium-vanadium steel. 4. Stainless steel (18/8). 5. Stainless steel (12–14 per cent. chromium). 6. Music wire. Loss in load is not more than 2 per cent.

Square Wires.—We may now turn to the square wires. For calculating the stress, the formula used is $S = \frac{2 \cdot 4PD}{d^3}$. Deflection is calculated by the aid of the formula $F = \frac{P5 \cdot 58D^3N}{Gd^4}$. With the aid of these two formulæ, it is possible to work out also wire size. In calculating solid height, the point to be remembered is that if any square spring is coiled to a small mean diameter, the square wire, when coiled, takes on a keystone form, the inner side of the wire becoming broader than the outer. Thus, the wire's cross section has a trapezoidal form. Obviously, then, it is not possible to calculate correctly the solid height of the spring from the wire size, and a new formula has to be used, for which we are indebted to Stewart (*S.A.E. Journal*, August 1925). This is as follows:

$$d_1 = 0 \cdot 48d \left\{ \frac{\text{O.D.}}{\text{P.D.}} + 1 \right\}$$

(In those instances in which the ratio of wire diameter to mean spring diameter is larger than 1 : 12, the keystone effect becomes negligible and the formula valueless.) It is possible to compute the solid height of the spring once the value of d_1 is obtained. In this formula, O.D. is the external diameter of the spring, P.D. the pitch diameter in inches; d the original wire size, and d_1 the width of wire inside after being coiled.

The table on page 1071 gives formulæ for round and square wire, as arranged by Messrs. Barnes, Gibson, Raymond, of Detroit, and also gives suggested total stresses.

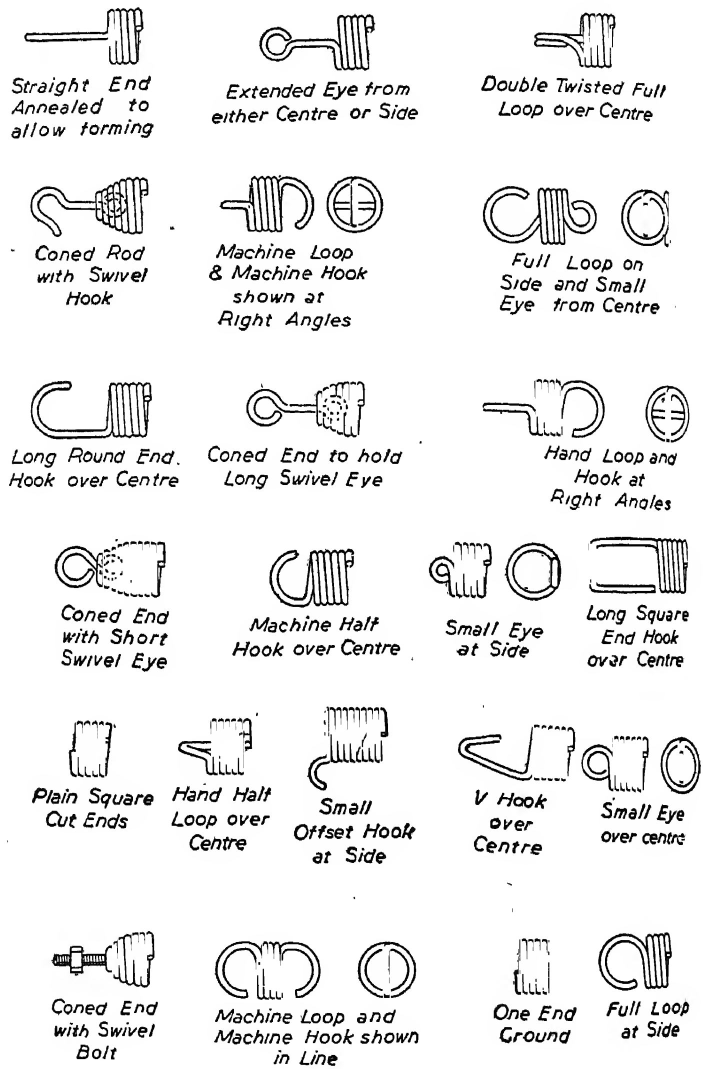


Fig. 6.—Spring ends for extension springs.

See Riley about Springs

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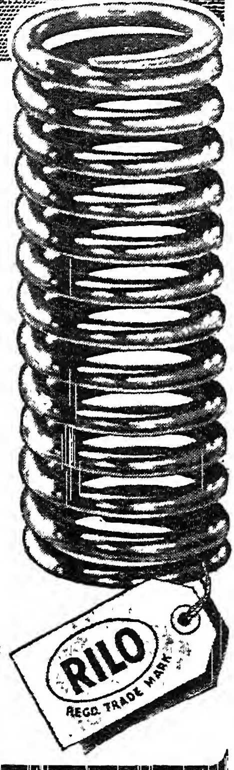

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In connection with the table on page 1071, it must be remembered that these stresses are not absolute. The narrower the range of stress, the greater will be the safety margin of the spring. If feasible, it is better to design springs in such a manner that the stress range is never more than $\frac{1}{2}$–$\frac{2}{3}$ the maximum working stress. Thus, a spring stressed at 25,000–60,000 from oil-tempered wire will normally give many millions of load applications, so long as corrosion does not affect it; in which case its life will inevitably be uncertain. Anti-corrosion treatment of springs is thus desirable.

Influence of Temperature.—Figs. 4 and 5 on pages 1066 and 1067 show the influence of temperature on stress, and have been compiled by the well-known firm of spring manufacturers previously mentioned. They indicate the combinations of stress and temperature necessary to create load losses of 2 per cent. and 10 per cent. for different spring materials. The greater the allowable loss of load, the higher is the temperature at which any given material may be employed. For the carbon- and chrome-vanadium steels, stress is the most vital factor at temperatures lower than 205° C. At higher temperatures than this, it is not safe to employ these steels. It will be seen that it is not safe to employ any of these materials at working temperatures of over 315° C. The stresses represented were computed by means of the Wahl formula, and are therefore total shear stresses. Where the working temperatures are likely to exceed those indicated in the diagrams, different materials will have to be employed, and are available for temperatures up to 425° C. It is advisable to consult the spring maker before specifying any particular spring material for use under these conditions.

We next come to rectangular-section wire, the calculations for which do not differ greatly from those for round wire. Deflection is calculated from the formula $F = \frac{2\pi NPR^3}{Bbc^3G}$. In this formula b is width and c is thickness. The other symbols are as in previous formulæ. Stress is calculated from the formula $S = \frac{PR}{Xbc^2}$. Values of X and B for various ratios of $\frac{b}{c}$ will be found on page 1071. The Wahl constant does not hold for rectangular sections, though it holds good for square and round. New constants can be developed from the original data, if desired, by the spring manufacturers.

Conical Springs.—Evenly tapered or conical springs can be calculated from the formula already provided, so long as the maximum mean diameter or radius is substituted in the stress formulæ. In the deflection formulæ it is necessary to employ the average mean diameter of the spring. At the same time, the reader must bear in mind that in both instances the formulæ will hold good only when the deflection is small enough so that one coil does not become inactive wire as a result of touching another.

When a spring of this type has deflected sufficiently to eliminate one coil, deflection per coil for the spring can once more be computed, employing the average mean diameter of the still active portion of the spring. A kindred method would solve rectangular-wire springs. The barrel-shaped springs, which have their maximum diameter in the middle, or those of hour-glass shape, with the minimum diameter in the middle, can be solved by making them represent two conical springs or by obtaining the precise mean diameter and substituting in the formulæ given.

We may now turn to the effect of suddenly applied load. On both extension and compression springs, it is often essential that the designer should calculate not only the influence of loads applied slowly but also that of those suddenly applied, as well as those applied by bodies possessing kinetic energy. These are complex calculations, because one term of the formula is often unknown, i.e. the velocity. Nevertheless the force exerted on the spring multiplied by the space exactly equals the amount of energy the spring absorbs, so that it is not difficult to work out the answer. This ignores hysteresis of the spring, of course. The undermentioned formulæ are then applicable:

(1) For loads applied very slowly: $F = \frac{P}{W}$.

(2) For loads applied suddenly: $F = \frac{2P}{W}$.

(3) For loads allowed to fall from a specified height: $F^2 = \frac{2P(s + F)}{W}$.

Here W is the rate per inch of spring deflection; P is the load on the spring; and s is the height in inches the load is allowed to fall.

Stress and Deflection.—In a few instances, springs are made from wire of special forms or sections. For these certain formulæ have been worked out by manufacturers for stress and deflection, as under:

(1) For elliptical wire: $S = \frac{16PR}{\pi e^2 h}$. $F = \frac{8(\pi)^3 PR^3 I_p N}{A^4 G}$. Here, e is the minor axis of ellipse, h the major axis of ellipse, I_p is $\frac{\pi}{64}(eh^3 + e^3h)$, A is $\frac{eh}{4}$.

(2) For triangular wire of equilateral section: $S = \frac{20PR}{g^3}$. $F = \frac{92{\cdot}4PR^3N(\pi)}{g^4G}$. Here, g is the base of the triangle.

(3) For octagonal wire: $S = \frac{PR}{0{\cdot}223Ai}$. $F = \frac{2PR^3N(\pi)}{0{\cdot}130Ai^2G}$. Here, i is the diameter of an inscribed circle in the octagon; N is the number of coils; R the pitch radius, I_p is the polar moment of inertia, and A is the area.

(4) For hexagonal wire: $S = \frac{PR}{0{\cdot}217Ai}$. $F = \frac{2PR^3N(\pi)}{0{\cdot}133Ai^2G}$.

A new set of formulæ comes into play: $n = 531\sqrt{R/W}\,{}^{\Omega}_{\upsilon}\frac{826,500d}{ND^2}$. In this formula, n is the complete number of free vibrations per minute of the spring as vibrating in itself; R is the rate of the spring; W is the weight of the active mass in the spring; d is the wire diameter; D is the pitch or mean diameter of the spring, and N is the number of active coils. The other, stated by L. F. G. Simonds in Paper No. 241 of the Advisory Committee for Aeronautics of Great

TOTAL STRESSES FOR TORSIONAL SPRINGS

	Wire Size below ⅛-in. dia.		*Wire Sizes ⅛ in.–¼ in.*	
	Max. Working Stress lb. per sq. in.	*Max. Total Stress lb. per sq. in.*	*Max. Working Stress lb. per sq. in.*	*Max. Total Stress lb. per sq. in.*
Music wire	170,000	200,000	150,000	180,000
Oil-tempered wire	150,000	180,000	125,000	150,000
Hard-drawn wire	130,000	150,000	110,000	130,000
18/8 stainless steel	130,000	150,000	100,000	120,000
Monel metal	50,000	70,000	40,000	60,000
Phosphor bronze	50,000	70,000	40,000	60,000
Brass	40,000	60,000	30,000	50,000
STRESSES FOR FLAT SPRINGS IN SECTIONS UNDER ⅛ IN. THICK				
Steel	150,000	20,000	—	—
Non-ferrous alloys	40,000	60,000	—	—

FORMULA FOR ROUND AND SQUARE WIRE

	Load Carried (1)	*Load Carried* (2)	*Deflection per Coil* (1)	*Deflection per Coil* (2)	*Deflection in in.*	*Stress* (1)	*Stress* (2)	*Wire Diameter* (1)	*Wire Diameter* (2)	*P lb. F (scale) per in. Deflection*
Round	$\frac{\pi S d^3}{8D}$	$\frac{Gfd^4}{8D^3}$	$\frac{\pi SD^2}{Gd}$	$\frac{8PD^3}{Gd^4}$	$\frac{8PD^3N}{Gd^4}$	$\frac{8PD}{\pi d^3}$	$\frac{fGd}{\pi d^2}$	$\frac{\pi D^2 S}{Gf}$	$\sqrt[3]{\frac{8PD}{\pi S}}$	$\frac{Gd^4}{8D^3N}$
Square	$\frac{0{\cdot}416Sd^3}{D}$	$\frac{Gfd^4}{5{\cdot}58D^3}$	$\frac{2{\cdot}325D^2}{Gd}$	$\frac{5{\cdot}58D^3P}{Gd^4}$	$\frac{5{\cdot}58D^3NP}{Gd^4}$	$\frac{2{\cdot}4PD}{d^3}$	$\frac{fGd}{2{\cdot}32D^2}$	$\frac{2{\cdot}32SD^2}{Gf}$	$\sqrt[3]{\frac{2{\cdot}4PD}{S}}$	$\frac{Gd^4}{5{\cdot}58D^3N}$

TOTAL STRESSES

	Steel Music Wire lb. per sq. in.	*Steel Wire Oil Tempered lb. per sq. in.*	*Hard-drawn Spring-steel Wire lb. per sq. in.*	*Stainless-steel Wire lb. per sq. in.*	*Monel Metal lb. per sq in.*	*Phosphor Bronze lb. per sq. in.*	*Brass lb. per sq. in.*
Max. Working Stress	70,000	60,000	50,000	50,000	35,000	35,000	25,000
Max. Solid Stress	120,000	100,000	80,000	80,000	70,000	70,000	50,000

VALUES OF X AND B FOR VARIOUS RATIOS OF $\frac{b}{c}$

$\frac{b}{c}$	*1·0*	*1·5*	*1·75*	*2·0*	*2·5*	*3·0*	*4·0*	*6·0*	*8·0*	*10·0*	*Infinite*
X	0·208	0·231	0·239	0·246	0·258	0·267	0·282	0·299	0·307	0·313	0·333
B	0·141	0·196	0·214	0·229	0·249	0·263	0·281	0·299	0·307	0·313	0·333

Britain, is: $n = \frac{1}{LP}\sqrt{\frac{WN}{8\pi Po}}$. Here, L is the total length of wire in the spring; W the sectional area; P the principal radius of curvature; N the modulus of rigidity 11,500,000; and Po is the density, i.e. $\frac{1}{365}$, for steel. It is also possible to express this as frequency per minute $= \frac{62{\cdot}4dBN}{R^2X}$. Here, X is the effective length of the spring in inches; R the mean radius of the coil in inches; B the pitch of coil in inches. In calculating X, it should be remembered that it is the length excluding any closed portion of the spring at each end.

Torsion Springs.—Load in torsion springs is governed by the location of the ends. The ends vary, as a result of winding or coiling, in accordance with the variation in the number of coils and diameter of wire to spring diameters. Springs of this type manufactured from wire of 0·044–0·062-in. diameter, and having fewer than four coils, could have their ends maintained in free position within 10–20 degrees. If, however, the number of coils were increased to 10–15, there might be a variation of 30–50 degrees. The length of straight ends is governed in variation by the recoil of the material, and this variation is usually between $\frac{1}{64}$ in. and $\frac{3}{32}$ in. One end can be kept to rather narrower tolerances than the other because of cut-off mechanism. This will be the long end, should different lengths be desired. For accurate length it will be essential to trim.

Most torsion springs are close wound. If room is required between the coils, it should be indicated as an approximate dimension. In designing this type of spring there are usually three known factors, namely load, movement, and space allowed. Load in the spring is controlled by wire dimension and movement (in degrees or number of turns), by length of wire (number of coils). Load should be applied in such a way that the spring winds up to a less diameter than its free diameter.

If coiled section is closely coiled, it extends in service, and provision for this must be taken into account. Space provided for springs can be occupied to a certain degree by space between coils to increase over-all length in free position. The internal diameter of the spring must be adequate in size to prevent it from folding or curling upon the rod or pin. This, if permitted to occur, will either bend or fracture the spring ends.

The torsion spring is normally manufactured from round wire, though on occasion square or rectangular wire wound on the edge is used. This type is usually employed in appliances where it is desired to exert pressure in a revolving direction about its axis, as for spring hinges, or brush holders on electrical motors and generators. They are also employed, where movement is restricted, for the purpose of applying pressure at right angles to their axes, as when used in latches or bolts of cheap locks. The rectangular sections wound on the edge are used in door-closing appliances or for starter springs on automobiles.

In most instances they operate about a rod, but can also be used to set up friction by a braking action, as when expanded in a container or tube. An additional application is to exert energy or power in small spring motors for toys, and they have also been employed to counterbalance domestic oven doors and garage doors of the lift type.

It will be seen from this that torsion springs are by no means to be regarded as standardised parts, and the manufacturer must know exactly what he is called upon to supply before he can deal effectively with any order or inquiry. A sample should be sent in every instance if it is at all feasible, and if this is impracticable then a fully dimensioned sketch or blue print must be provided. Furthermore, an indication of the circumstances in which the spring will have to work should be stated. If nothing to the contrary is said, the manufacturer will supply round wire.

Diameters should be stated as maximum external or minimum internal, and if the spring works around a rod, the rod diameter must be stated. The length of the coiled section must be declared, or the approximate number of coils. If loads are desired, the drawing should indicate the free position of the ends and the location of the ends under load. This should be shown in terms of degrees or number of turns. The point at which load is applied to the ends should be shown as distance in inches from the centre line of the axis of the coiled section.

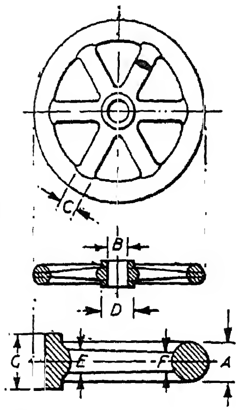


Fig. 1.—Large handwheels. See Table 1.

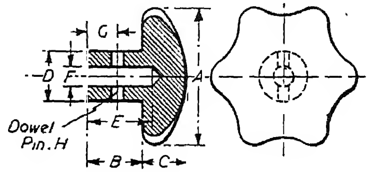


Fig. 2.—Machine doorknobs. See Table 2.

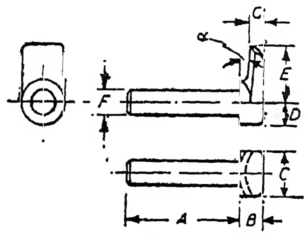


Fig. 3.—Machine door latches. See Table 3.

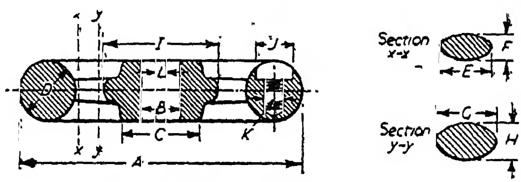


Fig. 4.—Straight-arm handwheels. See Table 4.

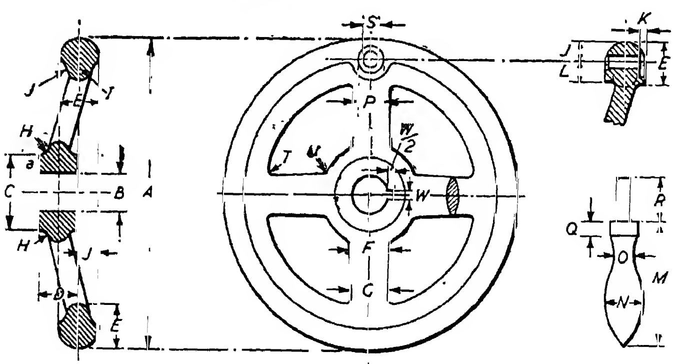


Fig. 5.—Machine handwheels. See Table 5.

TABLE 1

LARGE HANDWHEEL PROPORTIONS

(See Fig. 1)

Diam.	*A*	*B*	*C*	*D*	*E*	*F*	*G*
8	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$1\frac{1}{8}$
9	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	$1\frac{5}{8}$	$\frac{13}{32}$	$\frac{11}{32}$	$1\frac{1}{4}$
10	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{7}{16}$	$\frac{3}{8}$	$1\frac{5}{16}$
11	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{4}$	$1\frac{7}{8}$	$\frac{15}{32}$	$\frac{3}{8}$	$1\frac{3}{8}$
12	1	1	$\frac{13}{16}$	2	$\frac{1}{2}$	$\frac{13}{32}$	$1\frac{1}{2}$
13	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{15}{16}$	$2\frac{1}{8}$	$\frac{17}{32}$	$\frac{13}{32}$	$1\frac{5}{8}$
14	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$2\frac{1}{4}$	$\frac{9}{16}$	$\frac{7}{16}$	$1\frac{11}{16}$
15	$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{15}{16}$	$2\frac{3}{8}$	$\frac{19}{32}$	$\frac{15}{32}$	$1\frac{3}{4}$
16	$1\frac{1}{4}$	$1\frac{1}{4}$	1	$2\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$	$1\frac{7}{8}$
17	$1\frac{5}{16}$	$1\frac{5}{16}$	1	$2\frac{5}{8}$	$\frac{21}{32}$	$\frac{1}{2}$	$1\frac{15}{16}$
18	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{16}$	$2\frac{3}{4}$	$\frac{11}{16}$	$\frac{17}{32}$	$2\frac{1}{16}$
19	$1\frac{7}{16}$	$1\frac{7}{16}$	$1\frac{1}{8}$	$2\frac{7}{8}$	$\frac{23}{32}$	$\frac{9}{16}$	$2\frac{1}{8}$
20	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{16}$	3	$\frac{3}{4}$	$\frac{19}{32}$	$2\frac{1}{4}$
21	$1\frac{9}{16}$	$1\frac{9}{16}$	$1\frac{1}{4}$	$3\frac{1}{8}$	$\frac{25}{32}$	$\frac{5}{8}$	$2\frac{5}{16}$
22	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$3\frac{1}{4}$	$\frac{13}{16}$	$\frac{5}{8}$	$2\frac{7}{16}$
23	$1\frac{11}{16}$	$1\frac{1}{6}$	$1\frac{5}{16}$	$3\frac{3}{8}$	$\frac{27}{32}$	$\frac{21}{32}$	$2\frac{1}{2}$
24	$1\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{3}{8}$	$3\frac{1}{2}$	$\frac{7}{8}$	$\frac{11}{16}$	$2\frac{5}{8}$
27	$1\frac{15}{16}$	$1\frac{15}{16}$	$1\frac{1}{2}$	$3\frac{7}{8}$	$\frac{31}{32}$	$\frac{3}{4}$	$2\frac{7}{8}$
30	$2\frac{1}{8}$	$2\frac{1}{8}$	$1\frac{5}{8}$	$4\frac{1}{4}$	$1\frac{1}{16}$	$\frac{13}{16}$	$3\frac{3}{16}$
33	$2\frac{5}{16}$	$2\frac{5}{16}$	$1\frac{3}{4}$	$4\frac{5}{8}$	$1\frac{5}{32}$	$\frac{7}{8}$	$3\frac{7}{16}$
36	$2\frac{1}{2}$	$2\frac{1}{2}$	2	5	$1\frac{1}{4}$	1	$3\frac{3}{4}$

TABLE 2

MACHINE DOORKNOBS

(See Fig. 2)

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
$2\frac{1}{4}$	$1\frac{1}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$1\frac{1}{4}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{3}{16} \times \frac{15}{16}$
2[illegible]	$1\frac{1}{16}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{16} \times 1\frac{1}{16}$
3[illegible]	$1\frac{1}{16}$	$\frac{15}{16}$	1	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{16} \times 1\frac{1}{16}$

TABLE 3

MACHINE DOOR LATCHES

(See Fig. 3)

A	*B*	*C*	*D*	*E*	*F*	*G*	α
2	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	1	$\frac{7}{16}$	[illegible]	$8°$
2	$\frac{7}{16}$	[illegible]	$\frac{3}{8}$	1	$\frac{1}{2}$	[illegible]	$8°$
2	$\frac{1}{2}$	[illegible]	$\frac{7}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	$8°$

TABLE 4

STRAIGHT-ARM HANDWHEELS

(See Fig. 4)

No. of arms: 4 up to the 10-in. size; 5 in the 11-in. size; 6 in the 12-in. size.

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	K	*L*
4	$\frac{3}{8}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{16}$	$1\frac{3}{8}$	$\frac{15}{32}$	$\frac{5}{16}$	$\frac{1}{16} \times \frac{1}{32}$
5	$\frac{7}{16}$	1	$\frac{13}{16}$	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{11}{16}$	$\frac{11}{32}$	$1\frac{5}{8}$	$\frac{15}{32}$	$\frac{3}{8}$	$\frac{3}{32} \times \frac{3}{64}$
6	$\frac{9}{16}$	$1\frac{3}{16}$	$\frac{15}{16}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	$1\frac{7}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{32} \times \frac{3}{64}$
7	$\frac{11}{16}$	$1\frac{3}{8}$	1	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{7}{8}$	$\frac{7}{16}$	$2\frac{1}{8}$	$\frac{19}{32}$	$\frac{3}{8}$	$\frac{1}{8} \times \frac{1}{16}$
8	$\frac{3}{4}$ to $\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{15}{16}$	$\frac{15}{32}$	$2\frac{3}{8}$	$\frac{19}{32}$	$\frac{3}{8}$	$\frac{1}{8} \times \frac{1}{16}$
9	$\frac{13}{16}$ to 1	$1\frac{5}{8}$	$1\frac{3}{16}$	$\frac{13}{16}$	$\frac{13}{32}$	1	$\frac{1}{2}$	$2\frac{5}{8}$	$\frac{19}{32}$	$\frac{3}{8}$	$\frac{1}{8} \times \frac{1}{16}$
10	$\frac{7}{8}$ to 1	$1\frac{3}{4}$	$1\frac{5}{16}$	$\frac{7}{8}$	$\frac{7}{16}$	$1\frac{1}{8}$	$\frac{9}{16}$	$2\frac{7}{8}$	$\frac{21}{32}$	$\frac{7}{16}$	$\frac{3}{16} \times \frac{3}{32}$
11	$\frac{15}{16}$ to $1\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{3}{8}$	$\frac{15}{16}$	$\frac{15}{32}$	$1\frac{3}{16}$	$\frac{9}{16}$	$3\frac{1}{8}$	$\frac{21}{32}$	$\frac{7}{16}$	$\frac{3}{16} \times \frac{3}{32}$
12	1 to $1\frac{1}{4}$	2	$1\frac{1}{2}$	1	$\frac{1}{2}$	$1\frac{1}{4}$	$\frac{5}{8}$	$3\frac{3}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4} \times \frac{1}{8}$

TABLE 5

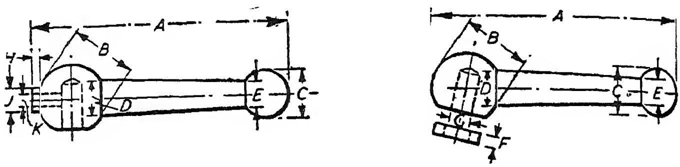
MACHINE HANDWHEELS

(See Fig. 5)

No of arms: 4 for sizes up to and including 12 in.; 6 for larger sizes.

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*
6	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{25}{32}$	$\frac{7}{32}$	$\frac{3}{16}$	$\frac{7}{16}$	$\frac{3}{32}$	$\frac{5}{16}$
8	$\frac{7}{8}$	$1\frac{7}{8}$	1	$1\frac{1}{8}$	1	$\frac{27}{32}$	$\frac{1}{4}$	$\frac{13}{64}$	$\frac{1}{2}$	$\frac{3}{32}$	$\frac{3}{8}$
10	1	$2\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{9}{32}$	$\frac{7}{32}$	$\frac{9}{16}$	$\frac{5}{32}$	$\frac{1}{2}$
12	$1\frac{1}{8}$	$2\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{3}{8}$	$1\frac{3}{32}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{9}{16}$
14	$1\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{16}$	$\frac{11}{32}$	$\frac{9}{32}$	$\frac{11}{16}$	$\frac{1}{4}$	$\frac{9}{16}$
16	$1\frac{3}{8}$	$2\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{3}{4}$	..	..
18	$1\frac{1}{2}$	3	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{3}{16}$	$\frac{13}{32}$	$\frac{3}{8}$	$\frac{13}{16}$	..	..

A	*M*	*N*	*O*	*P*	*Q*	*R*	*S*	*T*	*U*	*W*	*Size of Woodruff Key*
6	$2\frac{1}{2}$	1	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{32}$	6
8	$2\frac{3}{4}$	$1\frac{1}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{8}$	$1\frac{1}{16}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{9}{16}$	$\frac{3}{16}$	11
10	$3\frac{1}{8}$	$1\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$1\frac{3}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{4}$	15
12	$3\frac{3}{8}$	$1\frac{3}{8}$	$\frac{3}{4}$	1	$\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{2}$	$\frac{11}{32}$	$\frac{11}{16}$	$\frac{1}{4}$	18
14	$3\frac{5}{8}$	$1\frac{3}{8}$	$\frac{3}{4}$	1	$\frac{1}{2}$	$1\frac{3}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{5}{16}$	D
16	..	..	..	..	..	..	..	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	23
18	..	..	..	..	..	..	..	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	F



Figs. 6 and 7.—Clamping levers. See Table 6.

TABLE 6

CLAMPING LEVERS

(See Figs. 6 and 7)

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*
$4\frac{1}{2}$	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{5}{16}$
$5\frac{1}{2}$	$1\frac{1}{2}$	1	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{8}$	[illegible]	[illegible]
$6\frac{1}{2}$	$1\frac{3}{4}$	1	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{16}$	[illegible]	[illegible]
$7\frac{1}{2}$	$1\frac{3}{4}$	1	$\frac{3}{4}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{5}{8}$	[illegible]
$8\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{11}{16}$	$\frac{7}{16}$
9	$1\frac{3}{4}$	$1\frac{3}{16}$	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{11}{16}$	$\frac{7}{16}$

TABLE 7

COMPOUND-REST HANDLES

(See Fig. 8)

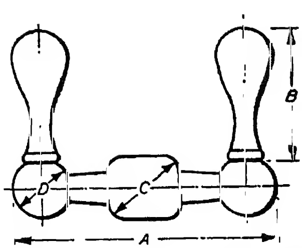


Fig. 8.—Compound-rest handles. See Table 7.

A	*B*	*C*	*D*
$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
3	$1\frac{1}{2}$	$1\frac{1}{16}$	$\frac{3}{4}$
3	$1\frac{1}{2}$	$1\frac{1}{16}$	$\frac{3}{4}$
3	$1\frac{1}{2}$	$1\frac{1}{16}$	$\frac{3}{4}$
$3\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
$3\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
$3\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{16}$	$\frac{3}{4}$
4	2	$1\frac{3}{16}$	$\frac{7}{8}$
4	2	$1\frac{3}{16}$	$\frac{7}{8}$
4	2	$1\frac{3}{16}$	$\frac{7}{8}$

Table 8
Machine Handles
(See Fig. 9)

A	B	C	D	E	F	G	A	B	C	D	E	F	G
$1\frac{13}{16}$	$1\frac{15}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{7}{32}$	$\frac{3}{32}$	$\frac{9}{32}$	4	$3\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{17}{32}$	$\frac{3}{16}$	$\frac{11}{16}$
2	$1\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{32}$	$\frac{5}{16}$	$4\frac{3}{8}$	$3\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{9}{16}$	$\frac{3}{16}$	$\frac{23}{32}$
$2\frac{1}{4}$	$1\frac{3}{4}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{1}{8}$	$\frac{3}{8}$	$4\frac{5}{8}$	$3\frac{5}{8}$	1	$1\frac{3}{16}$	$\frac{19}{32}$	$\frac{7}{32}$	$\frac{13}{16}$
$2\frac{3}{4}$	$2\frac{1}{8}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{1}{8}$	$\frac{7}{16}$	$5\frac{1}{8}$	$4\frac{1}{8}$	1	$1\frac{3}{8}$	$\frac{11}{16}$	$\frac{7}{32}$	$\frac{7}{8}$
$3\frac{1}{8}$	$2\frac{3}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{5}{32}$	$\frac{1}{2}$	$5\frac{3}{4}$	$4\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{3}{4}$	[illegible]	$\frac{31}{32}$
$3\frac{1}{2}$	$2\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{5}{32}$	$\frac{9}{16}$	6	$4\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{9}{16}$	$\frac{25}{32}$	[illegible]	$1\frac{1}{32}$

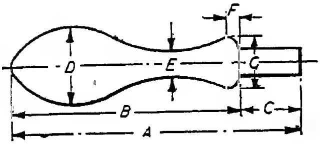


Fig. 9.—Machine handles. See Table 8.

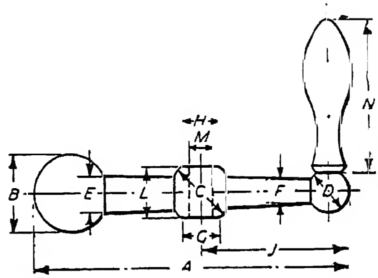
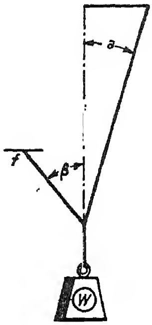


Fig. 10.—Balanced machine handles. See Table 9.

Table 9
Balanced Machine Handles
(See Fig. 10)

A	B	C	D	E	F	G	H	J	L	M	N
3	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	$1\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$1\frac{1}{2}$
$3\frac{1}{4}$	$\frac{15}{16}$	$\frac{25}{32}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$1\frac{5}{8}$	$\frac{9}{16}$	$\frac{5}{16}$	$1\frac{5}{8}$
$3\frac{1}{2}$	$1\frac{1}{16}$	$\frac{29}{32}$	$\frac{3}{4}$	$\frac{15}{32}$	$\frac{11}{32}$	$\frac{5}{8}$	$\frac{9}{16}$	$1\frac{3}{4}$	$\frac{11}{16}$	$\frac{3}{8}$	$1\frac{3}{4}$
4	$1\frac{1}{4}$	1	$\frac{3}{4}$	$\frac{17}{32}$	$\frac{13}{32}$	$\frac{3}{4}$	[illegible]	2	$\frac{3}{4}$	$\frac{7}{16}$	$1\frac{7}{8}$
$4\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{3}{32}$	$\frac{27}{32}$	$\frac{19}{32}$	$\frac{7}{16}$	[illegible]	[illegible]	$2\frac{1}{4}$	$\frac{13}{16}$	$\frac{1}{2}$	2
5	1 [illegible]	$1\frac{5}{16}$	1	$\frac{3}{4}$	$\frac{1}{2}$	[illegible]	[illegible]	$2\frac{1}{2}$	1	[illegible]	$2\frac{3}{16}$
$5\frac{1}{2}$	1 [illegible]	$1\frac{5}{16}$	1	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{8}$	[illegible]	$2\frac{3}{4}$	1	[illegible]	$2\frac{3}{8}$
6	1 [illegible]	$1\frac{3}{8}$	1	$\frac{3}{4}$	$\frac{1}{2}$	1	[illegible]	3	1	[illegible]	$2\frac{9}{16}$
$6\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{8}$	1	$\frac{3}{4}$	$\frac{1}{2}$	1	[illegible]	$3\frac{1}{4}$	1	[illegible]	$2\frac{3}{4}$
7	$1\frac{3}{4}$	$1\frac{7}{16}$	1	$\frac{3}{4}$	$\frac{9}{16}$	1	[illegible]	$3\frac{1}{2}$	$1\frac{1}{16}$	[illegible]	$2\frac{15}{16}$
$7\frac{1}{2}$	$1\frac{3}{4}$	1 [illegible]	1	$\frac{3}{4}$	$\frac{9}{16}$	1	[illegible]	$3\frac{3}{4}$	$1\frac{3}{32}$	[illegible]	$3\frac{1}{8}$
8	1 [illegible]	1 [illegible]	$1\frac{1}{16}$	$\frac{3}{4}$	$\frac{9}{16}$	1	$\frac{15}{16}$	4	$1\frac{1}{8}$	[illegible]	$3\frac{5}{16}$
$8\frac{1}{2}$	1 [illegible]	$1\frac{9}{16}$	$1\frac{1}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$4\frac{1}{4}$	$1\frac{3}{16}$	$\frac{3}{4}$	3 [illegible]
9	1 [illegible]	$1\frac{5}{8}$	$1\frac{3}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$4\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$	3 [illegible]

PARALLELOGRAM OF FORCES



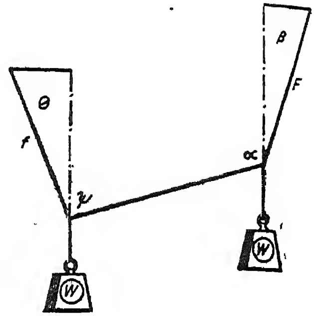
$$W : F = \sin(a + \beta) : \sin\beta$$

$$W : f = \sin(a + \beta) : \sin a$$

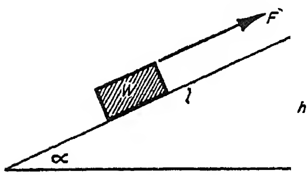
$$F = \frac{W \sin\beta}{\sin(a + \beta)}$$

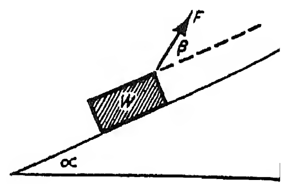
$$f = \frac{W \sin a}{\sin(a + \beta)}$$

$$W + F^2 + f^2 - 2Ff\cos(a + \beta)$$



$$F = \frac{W \sin\alpha}{\sin(\alpha + \beta)} \qquad f = \frac{W \sin\psi}{\sin(\alpha + \psi)}$$





Inclined Plane

No Friction

$$F = \frac{Wh}{l} = W\sin\alpha$$

$$W = \frac{Fl}{h} = \frac{F}{\sin\alpha}$$

No Friction

$$F = W\frac{\sin\alpha}{\cos\beta} \qquad W = F\frac{\cos\beta}{\sin\alpha}$$

With Friction

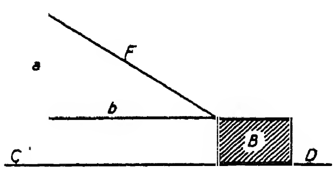
$$F = W\frac{\mu\cos\alpha + \sin\alpha}{\mu\sin\beta + \cos\beta}$$

where μ = coefficient of friction.

$$F = W\frac{\sin(\Phi + \alpha)}{\cos(\beta - \Phi)}$$

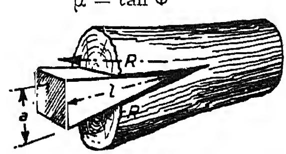
where Φ = limiting angle of resist.

$$\mu = \tan\Phi$$



Let line F represent the magnitude and direction of a force acting at an angle α to move the body B on line CD. Then the line a represents a part of F which presses the body B against CD. The line b represents the magnitude of the force which actually moves the body B.

$$b = \sqrt{F^2 - a^2} \qquad b = F\cos a$$

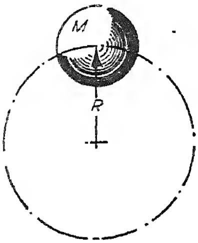


Wedge

$$F = \frac{Ra}{l} \qquad R = \frac{Fl}{a}$$

F = force required to drive the wedge.

CENTRIFUGAL FORCE AND TENSION

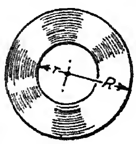


F = Centrifugal force in pounds.
M = Mass or weight of revolving body in pounds.
v = Velocity of revolving body in ft. per sec.
R = Radius of circle in which body revolves (ft.).
n = Number of revolutions per minute.
g = Coefficient of terrestrial acceleration = 32·2.
π = 3·1416.

$$F = \frac{Mv^2}{gR} = \frac{Mv^2}{32{\cdot}2R} \qquad F = \frac{4MR\pi^2 n^2}{60^2 g} = \frac{MRn^2}{2933}$$

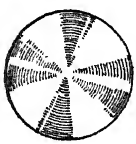
$$M = \frac{FgR}{v^2} = \frac{2933F}{Rn^2} \qquad R = \frac{Mv^2}{Fg} = \frac{2933F}{Mn^2}$$

$$n = \sqrt{\frac{2933F}{MR}} \qquad v = \sqrt{\frac{FRg}{M}}$$



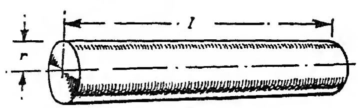
Centrifugal Tension (lb.) of a Ring—

$$\frac{Mn^2 \sqrt{R^2 + r^2}}{4150}$$



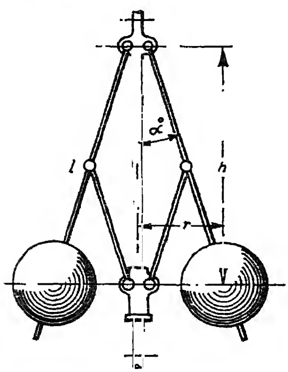
Centrifugal Tension of a Disc, Circle-plane, or Cylinder rotating round its centre:

$$\frac{MRn^2}{4150}$$



Centrifugal Tension of a Cylinder rotating round the diameter of its base—

$$\frac{Mn^2\sqrt{4l^2 + 3r^2}}{10{,}260}$$

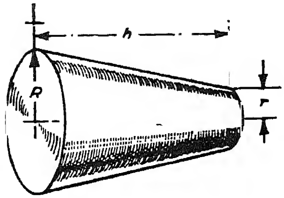


Governor

$$n = \frac{60}{2\pi}\sqrt{\frac{g}{h}} = \frac{54{\cdot}16}{\sqrt{h}} = \frac{54{\cdot}16}{\sqrt{l \cos a}}$$

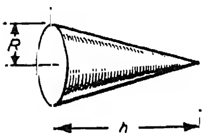
$$h = \frac{2933}{n^2} \qquad l = \frac{2933}{n^2 \cos a} = \frac{h}{\cos a}$$

$$\cos a = \frac{2933}{n^2 l} = \frac{h}{l} \qquad r = \sqrt{l^2 - h^2}$$

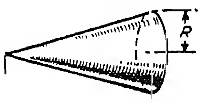


CONIC FRUSTUM

$$x = \sqrt{\frac{h}{10}\left(\frac{R^2 + 3Rr + Rr^2}{R^2 + Rr + r^2}\right) + \frac{3}{20}\left(\frac{R^5 - r^5}{R^3 - r^3}\right)}$$

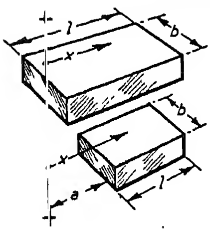


$$x = \sqrt{\frac{2h^2 + 3R^2}{20}}$$



$$= \sqrt{\frac{12h^2 + 3R^2}{20}}$$

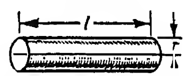
PARALLELOPIPED



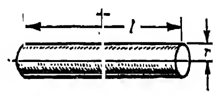
$$x = \sqrt{\frac{4l^2 + b^2}{12}}$$

$$x = \sqrt{\frac{4l^2 + b^2}{12} + a^2 + al}$$

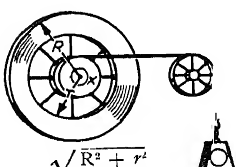
CYLINDER



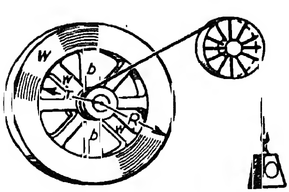
$$x = \sqrt{\frac{4l^2 + 3r^2}{12}}$$



$$x = \sqrt{\frac{l^2 + 3r^2}{12}}$$



$$x = \sqrt{\frac{R^2 + r^2}{2}}$$

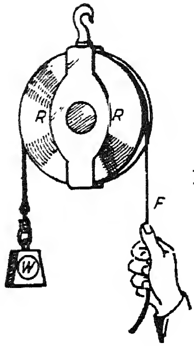


FLYWHEEL WITH ARMS

$$x^2\,(W + w) = W\,\frac{R^2 + r^2}{2} + w\,\frac{4r^2 + b^2}{12}$$

$$= \sqrt{\frac{6W(R^2 + r^2) + w(4r^2 + b^2)}{12(W + w)}}$$

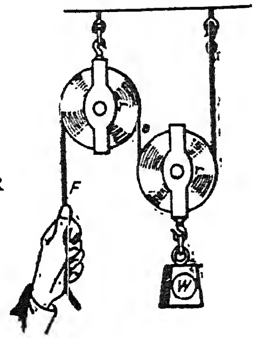
PULLEYS



SINGLE FIXED PULLEY

$F : W = R : R$
or $F = W$

$\frac{V^1}{V} = 1$

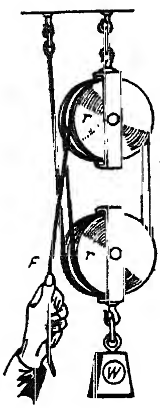


SINGLE MOVABLE PULLEY

$F : W = r : 2r$
or $F = \frac{1}{2}W$

Note.—If the force is applied at *a* and acts upward, the result will be the same.

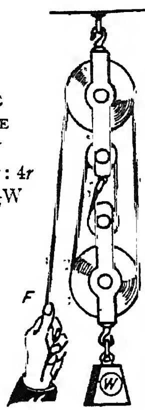
$\frac{V^1}{V} = 2$



DOUBLE MOVABLE PULLEY

$F : W = r : 4r$
or $F = \frac{1}{4}W$

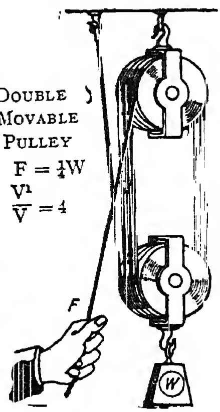
$\frac{V^1}{V} = 4$



DOUBLE MOVABLE PULLEY

$F = \frac{1}{4}W$

$\frac{V^1}{V} = 4$

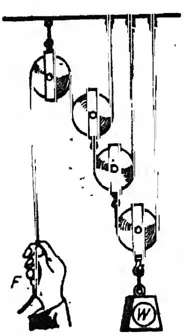


MULTIPLE MOVABLE PULLEY

If n = any number of movable pulleys:

$F = \frac{W}{2n}$

$\frac{V^1}{V} = 2n$



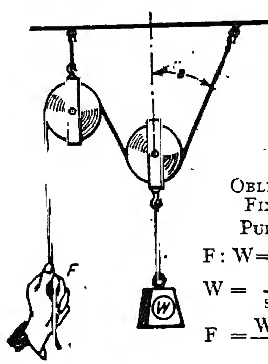
COMPOUND PULLEY

n = number of movable pulleys:

$F = \frac{W.}{2^n}$

$W = 2^n F$

$\frac{V^1}{V} = 2^n$



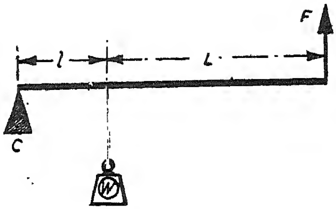
OBLIQUE FIXED PULLEY

$F : W = \sec a : 2$

$W = \frac{2F}{\sec a}$

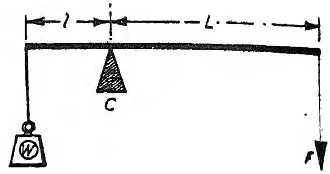
$F = \frac{W \sec a}{2}$

LEVERS



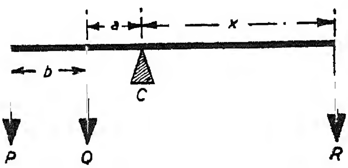
$$F : W = l : L \qquad FL = Wl$$

$$F = \frac{Wl}{L} \qquad W = \frac{FL}{l}$$



$$F : W = l : L \qquad FL = Wl$$

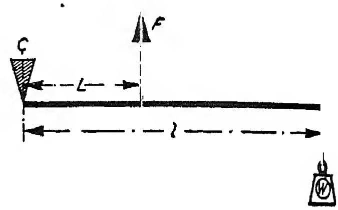
$$F = \frac{Wl}{L} \qquad W = \frac{FL}{l}$$



To find fulcrum C when three forces act on one lever.

$$Rx = Qa + P(b + a)$$

$$x = \frac{Qa + P(b + a)}{R}$$



$$F : W = l : L \qquad FL = Wl$$

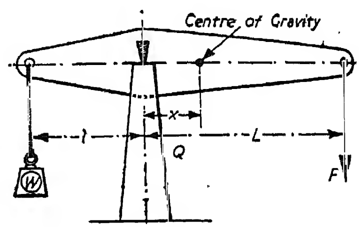
$$F = \frac{Wl}{L} \qquad W = \frac{FL}{l}$$

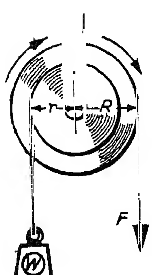
Q = Weight of the lever.

x = distance from centre of gravity of lever to fulcrum.

$$F = \frac{Wl - Qx}{L}$$

$$W = \frac{FL + Qx}{l}$$





$$F : W = r : R$$

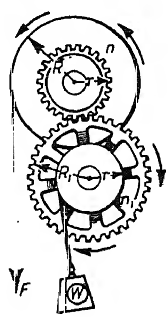
$$FR = Wr$$

$$F = \frac{Wr}{R}$$

$$R = \frac{Wr}{F}$$

$$W = \frac{RF}{r}$$

$$r = \frac{RF}{W}$$



$$F = \frac{Wrr'}{RR'}$$

$$W = \frac{FRR'}{rr'}$$

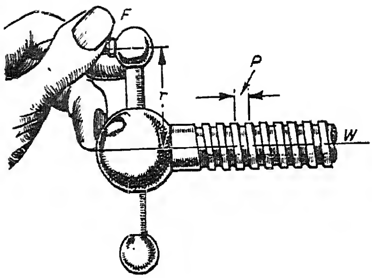
$n.n'$ = number of revolutions of the wheels.

$n : n' = R' : r.$

$V : V' = RR' = rr'.$

V = velocity of F.

V' = velocity of W.



FORCE EXERTED BY A SCREW

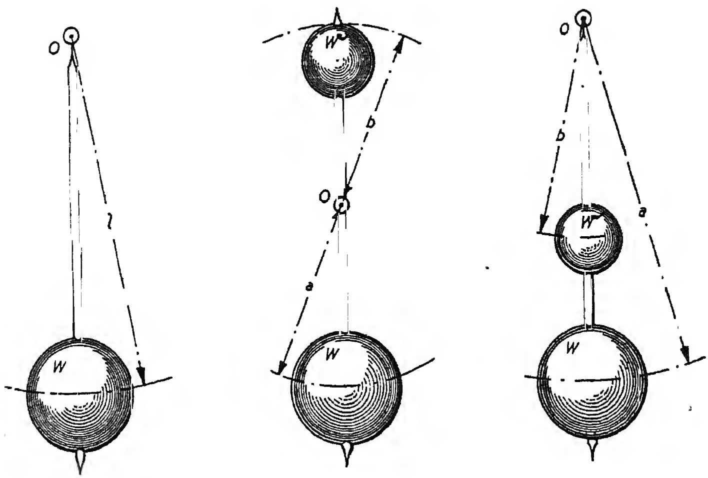
P = pitch of screw (distance between threads).

r = radius on which force F acts.

$\pi = 3{\cdot}1416.$

$$F : W = P : 2\pi r$$

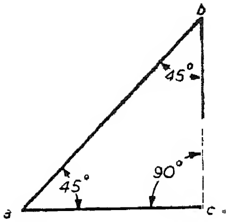
$$F = \frac{WP}{2\pi r} \qquad W = \frac{F2\pi r}{P}$$



Left, the Simple Pendulum, $t = \pi\sqrt{\frac{l}{g}}$; l = length of pendulum in inches; t = time in secs. of one oscillation; g = 32·097 ft. per sec. or 385·163 in. per sec. Time for complete oscillation (two swings) $= 2\pi\sqrt{\frac{l}{g}}$.

Centre, the Compound Pendulum, in which o = centre of suspension and l = equivalent length of simple pendulum to give same time of oscillation, $l = \frac{a^2W + b^2w}{aW - bw}$

Right, another form of Compound Pendulum, $l = \frac{a^2W + b^2w}{aW + bw}$

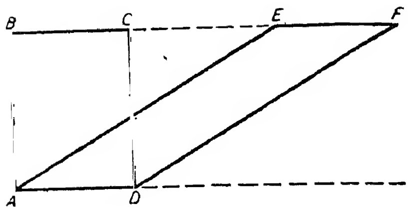


45° Right-angled Triangle

In a right-angled triangle with two equal acute anges, $bc = ac$

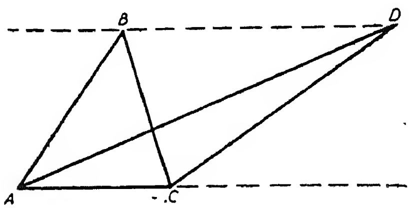
$bc = 1$, then $ab = \sqrt{2} \quad = 1{\cdot}414$

$ab = 1$, then $bc = \sqrt{0{\cdot}5} = 0{\cdot}707$



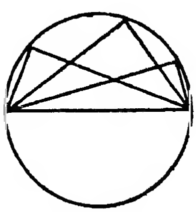
Parallelograms on Same Base

This shows that parallelograms on the same base and between the same parallels are equal in area; thus ABCD = AEFD.



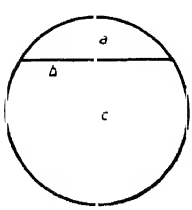
Triangles on Same Base

This demonstrates that triangles on the same base and between the same parallels are equal in area; thus ABC = ADC.



Triangles in Circle

All triangles constructed in a circle and having a diameter as a base are right-angled triangles.



Chord Intersected by Diameter

In this diagram:

$$a : b :: b : c, \text{ or } \frac{b^2}{a} = c$$

COMPRESSED AIR

The three principal parts of a compressed-air plant are the compressor, in which air is compressed to the desired pressure, the distributing mains for conveying the air from the compressor to the point of application, and the motor or plant being operated by the compressed air.

Compressors.—These are reciprocating, rotary, and centrifugal rotary or turbo type.

Reciprocating compressors are used when a supply of high-pressure air is required. The operating cycle is that air is drawn through the suction valve at low pressure, is compressed in the cylinder to the desired pressure, and then passed either directly to the distributing mains or to an air receiver or reservoir.

This type of compressor can be either single- or double-acting; being termed single-acting when air is admitted to one side of the piston only, and double-acting when air is admitted to both sides of the piston.

An essential feature of a well-designed reciprocating compressor is that the clearance between the piston and cylinder cover at the dead centres should be kept down to the lowest practical limits; for when the piston commences its suction stroke, all the air entrapped in the clearance space has to expand to initial atmospheric pressure before any air can be admitted to the cylinder. It is obvious that a large clearance will seriously affect the volumetric efficiency, because in cases of bad design admission cannot commence until the piston has travelled a considerable distance of its stroke.

Valve Design.—Valve design is also an important feature of compressor design, for unless valves are correctly designed they will give rise to excessive "valve hammering," with resultant noise, wear and, in many instances, considerable risk of breakage. Some of the desirable features in a valve for this purpose are: (1) large area of opening, with small lift; (2) no stout or stiff springs should be allowed in any valve—they should be long, light, preferably double and easy of access; (3) low inertia of all moving parts, avoiding excessive wear and noise; (4) delivery valves should be capable of remaining open to the end of the stroke, closing rapidly and opening again with the minimum of noise.

The "Rogler-Hoerbinger" patent valve is a typical example of a valve that is reliable and noiseless in action, requiring the minimum amount of power for operating. This consists of light discs of tempered steel perforated to give a multiple opening and arranged to fall on a cast-iron grid with suitable cushion and guard plates above.

Another essential feature is that the piston should be airtight, so the piston rings need very careful fitting, otherwise leakage past the rings will occur, with resultant loss of efficiency.

Laws Governing Compression.—The volume occupied by a gas such as air is inversely proportional to the absolute pressure. Thus, if the pressure is doubled the volume is halved, and conversely, if the volume is reduced by one-half the pressure is doubled.

Volume of a gas is proportional to its absolute temperature. To heat air is to increase its volume.

To express the volume changes due to pressure:

$$PV = RT$$

where P is pressure in lb. absolute (2,117 lb. per sq. ft. + p lb. per sq. ft.).

V is the volume of gas in cu. ft. per lb.

R is constant for the gas being compressed.

T is the absolute temperature in degrees F. ($460° + t°$).

The constants for air, ammonia, oxygen, and hydrogen are, respectively, 53·2, 93·31, 48·3, and 767·0, while their densities per cu. ft. are, respectively, 0·07658, 0·04487, 0·08460, and 0·00530, and with these figures one can work out the changes of volume for any alteration in pressure or temperature for the four gases in question.

When a gas is compressed it rises in temperature, while if it is allowed to expand it falls in temperature.

In effect there are two types of compression—adiabatic and isothermal. The former is one in which the heat generated does not escape quickly enough and the temperature of the gas rises. In the latter it is assumed that the heat is radiated as fast as it is formed, so that the temperature does not rise, although this is not possible without the use of coolers.

It is apparent that if the heat accumulates in the gas being compressed, a temperature factor is involved at the same time as the one for pressure in the formula given above. Therefore, to calculate in advance the ultimate volume of air, for example, after compression, this must be taken into account.

Empirical rules for reciprocating compressors are that the velocity of the air through the valve ports should not exceed 5,500 ft. per min., with a piston speed of 550 ft. per min., and a valve area equal to 10 per cent. of the piston area.

Power for Compression.—The smallest amount of power required to compress a known quantity of air to any pressure will be when the compression approaches the isothermal limit. If none of the heat of compression is absorbed, however, the compression rapidly approaches the adiabatic. The result of adiabatic compression would be expenditure of more work than is needed to compress the same volume of air isothermally; for example, to compress 10 cu. ft. of free air per minute to 100 lb. pressure isothermally (that is, to abstract the heat as it is generated) would need the expenditure of 1·31 h.p.; while to compress adiabatically, or without any heat loss occurring through the conduction of heat, would need 1·81 h.p. to carry out the same duties.

The aim in practice is to approach as near as possible to isothermal compression. The law of compression is in the form of PV^n, where $n = 1{\cdot}406$ for adiabatic and 1·0 for isothermal; or the nearer $n = 1{\cdot}0$ is approached, the more efficient will be the compressor. Various methods have been adopted to secure this needed air cooling and work reduction, such as by water-jacketing and spray injection.

Water-jacketing is effected by providing the cylinder and cylinder covers with water-jackets and removing the heat of compression by cooling water; the value of n for water cooling is commonly 1·3, while with injection, by which is meant injection of cold water into the cylinder, values for n as low as 1·2 have been secured.

When high efficiencies are desired, it is usual to carry out the compression in two or more stages, cooling the air between the stages. This is known as multi-stage compression and intercooling.

The result of this is that whereas the theoretical rise in temperature due to the compression of air at 60° F. to 100 lb. pressure is as high as 425° F., with intercoolers it may be less than 100° F.

The principle of operation is that the air is compressed in one cylinder, discharged to an intercooler wherein the heat of compression is removed, is passed to another cylinder, is compressed to a higher pressure, to be discharged either to a receiver or to another intercooler—this depending upon the number of stages, there being one less intercooler than cylinders in all-stage compression.

For small installations, single-stage compressors are invariably used, only large projects warranting the expense of a two- or more-stage machine—the limitation to the use of a single-stage compressor being approximately 200 cu. ft. of air per minute at a receiver pressure of 100 lb. per sq. in.

In cases where any moisture in the delivery air may cause inconvenience an after-cooler is fitted; this consists, in common with intercoolers, of a large number of thin parallel tubes, through which the air flows, totally immersed in water. These tubes provide a large cooling surface, so that water entrained in the air is condensed.

Receivers or Reservoirs.—It is generally desirable that a receiver is fitted, especially when the demand for the supply of compressed air is intermittent. These are usually plain cylindrical vessels of such a capacity that they are capable of holding a three- or four-minute compressor output, thereby forming a reservoir from which a supply of air is always available.

Empirical rules for proportion of air receivers, constructed of riveted mild-steel plates, for a pressure of 100 lb. per sq. in. (test pressure 200 lb. per sq. in.) are as follow:

$$H = 2D + 1 \qquad t = 1 + \tfrac{1}{16}d$$
$$C = \pi/4\,(2D^3 + D^2) \qquad T = 2 + \tfrac{1}{12}d$$
$$W = 80D^{2\cdot35}$$

where H = Height in feet.
D = Diameter in feet.
C = Capacity in cubic feet.
W = Weight in lb.
d = Diameter in inches.
t = Thickness of curved ends in $\frac{1}{16}$ in.
T = Thickness of sides in $\frac{1}{16}$ in.

Control.—Regulation of a compressor output is very largely dependent upon the drive employed; however, whatever form of drive is used it is often desirable to unload the compressor when a predetermined receiver or mains pressure has been reached, without the attendant difficulties of continuous stopping and starting. This is usually effected by fitting an equilibrium double-beat automatic valve to the air inlet, controlled by an air relay. On exceeding a predetermined pressure the air supply to the compressor is stopped, and does not resume its normal function until demand reduces the pressure in the air receiver. Control of steam-driven compressors is carried out by centrifugal governor and relay-type air governer, whereby combined speed and pressure regulation maintain approximately a constant pressure in the air receiver. In addition to fitting unloading devices, compressors operated by electric motors are usually fitted with pressure-operated stopping and starting devices.

Rotary Compressors.—These are employed when moderately small quantities of low-pressure air are required.

These usually consist of rotating blades arranged to slide in a rotor, which operates eccentrically in a stator or casing. The combination of sliding vanes in contact with the internal surface of the stator and eccentrically operating rotor has the effect of drawing in air when the blades are extended to their position, gradually compressing the air by reason of reducing volume until it is discharged at maximum pressure, or when the blades are in their innermost position.

A recent development of the rotary compressor is the helical lobe compressor. This machine combines the advantages of the gear and the conical screw type, having a positive compression between the lobes, and small dimensions; it may be run at very high speed, without too high losses. General characteristics of these three rotary compressors are: The gear-screw type or Roots blower has double end plates, and two three-threaded rotors, the lead being 60 degrees. The inlet is radial against the direction of rotation, with a radial outlet. The conical screw or Imo compressor has a free axial inlet and an inlet plate on the pressure side. A single-threaded male rotor meshes with a two-threaded female rotor. The lead of the male rotor is over 720 degrees. Free axial outlet is provided, with axial or radial outlet. The helical lobe or Lysholm compressor also has double end plates; in this case a three-lobed male rotor meshes with a three-lobed female rotor. The lead of lobes varies between 146 and 217 degrees. The inlet is either radial or axial plus radial and combined with axial and radial outlet, resulting in a diagonal flow.

As already stated, when large volumes of air at fairly high pressure are required, stage reciprocating compressors are invariably employed. However, when large-volume, reasonably low-pressure air is required, the turbo-compressor is used.

Centrifugal, Rotary, or Turbo Compressors.—These consist in the main of a number of rotating fans or impellers operating in series.

Each impeller rotates in a cell formed by two diaphragms arranged in the casing of the machine; the impeller transmits energy to the air, which is transformed so that a certain amount is expended in actual compression and the remainder as kinetic energy of the stream leaving the impeller. The outer diameter of the cells is larger than the impeller; therefore the air leaving this rotating part passes into an outer space which acts as a diffuser, in which the kinetic energy of the air stream is converted into pressure energy.

Operational speeds for single-stage compressors usually average between 2000 and 2800 r.p.m., although speeds as high as 22,000 r.p.m. have been attained. Multi-stage rotors usually operate at from 3500 to 5000 r.p.m.; these speeds are controlled by the type of driving unit used, and as the design of the impeller is dependent upon the rotational speed, maximum efficiency can be secured only by operating to design conditions.

Efficiency is also dependent upon the design and shape of the diffuser and transfer passages, impeller inlet design, construction and proportioning of air passages, bends, ports, packings, etc. A very efficient design of impeller is where the vanes are radial, and the inlet edges are shaped to form guide vanes to prevent

shock losses. As with reciprocating compressors, inter-stage cooling is resorted to, the most effective method being to cool between stages by means of external cooler of the surface-condenser type. There are various methods of effecting control and regulation, these being closely interlinked with the method of drive; that is, if driven by either steam turbine or electric motor. Advantages of drive by steam turbine are that where large quantities of exhaust steam are available the power necessary to drive the compressors can be derived from steam which would otherwise be blown to waste; alternatively they can be operated in line with boilers where large quantities of low-pressure steam are required for process purposes. Where turbine-driven compressor output can be governed by speed and no-load control, speed control can be secured automatically by operation of a compressed-air regulator, decreased demand causing a pressure rise which activates the regulator, which in turn operates the throttle valve of the turbine, causing a reduction in speed proportional to the increased air pressure at the regulator. Pressure decrease or increased demand operates in a reverse manner.

No-load and full-load control is effected by an automatic valve fitted to the suction side of the compressor. Regulation of compressors operated by alternating-current motors is carried out by means of automatic suction valves, or by air-release valves; however, when operated by direct-current motors, speed change can be efficiently secured by the means of speed-regulating gear, air-pressure operated.

Horse-power for Air Compression.—Reference should be made to standard text-books on thermodynamics for an extended understanding of the work expended on air compression. However, for everyday practical purposes this may be computed in the following manner for the most commonly employed air compressor—the reciprocating machine.

Commence by calculating the mean effective pressure: this is found from the expression:

$$\text{M.E.P.} \doteq \frac{n}{n-1} \times x \times Pa\left\{\left(\frac{Pc}{Pa}\right)^{\frac{n-1}{xn}} - 1\right\}$$

where Pa = Absolute pressure at inlet valves (lb. per sq. in.).
Pc = Absolute pressure at delivery valve (lb. per sq. in.).
x = Number of stages.
n = A coefficient = 1·25.

The indicated horse-power is then calculated from:

$$\text{I.H.P.} = \frac{\text{Displacement} \times 144}{33{,}000} \times \text{M.E.P.}$$

Where the displacement equals cylinder capacity multiplied by volumetric efficiency, assuming this to be 90 per cent., then the foregoing expression becomes:

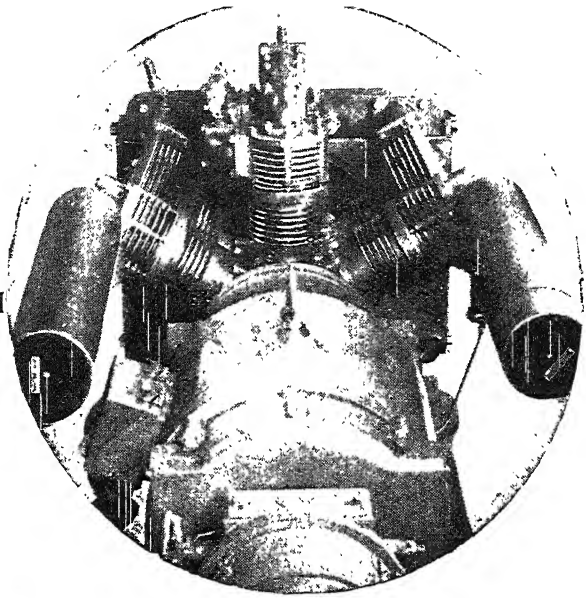
$$\text{I.H.P.} = \frac{\text{Capacity}}{206{\cdot}249} \times \text{M.E.P.}$$

The brake horse-power required to drive any known reciprocating compressor would for most practical purposes then be:

$$\frac{\text{I.H.P.}}{\text{Efficiency of drive}}.$$

It should be noted that the elevation above sea-level at which the compressor is to operate considerably affects plant efficiency, due to the consequent variation of atmospheric pressure.

The capacity of a compressor for a given duty will decrease approximately 3 per cent. for every 1000 ft. above sea-level. In calculating the transmission of power by compressed air, the maximum percentage of useful work between the cylinder of the compressor and the out-turn of the motor should be taken as not more than 30 per cent. It is usual to assume an efficiency of 85 per cent. for a direct-drive air compressor; 75 per cent. efficiency in compressing, 10 per cent. minimum loss per mile on the mains, and 50 per cent. efficiency of the compressed-air motor. Therefore an overall effective horse-power at the compressed-air motor, assuming a 100 indicated-horse-power drive at the compressor, will equal



$100 \times 0\cdot85 \times 0\cdot75 \times 0\cdot90 \times 0\cdot50 = 28\cdot69$ per cent. at a distance of one mile from the compressor.

Pressure Volume and Temperature.—When dealing with the use of compressed air it is often necessary to secure a knowledge of the state of the air after completing a process—such as expansion. As the pressure, volume, and temperature are closely related, calculation of conditions is a relatively simple matter, therefore to calculate the pressure or volume after an expansion process, the formula for the law of expansion is used, i.e. PV^n = a constant:

$$\therefore P_1V_1^n = P_2V_2^n.$$

where P_1 = Initial pressure (lb. per sq. ft.).
P_2 = Final pressure (lb. per sq. ft.).
V_1 = Initial volume (cu. ft.).
V_2 = Final volume (cu. ft.).
n = A coefficient = 1·25.

To find the final temperature use the relation :

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$$

where P_1, P_2, and n represent nomenclature already quoted, and
T_1 = Initial absolute temperature.
T_2 = Final absolute temperature.

$$\text{Work done} = \frac{P_1V_1 - P_2V_2}{n - 1}.$$

Heat is added to the air when the expansion curve is above the adiabatic curve, or the coefficient n is less than the ratio of the specific heat ; therefore as Y, the ratio of the specific heat, equals 1·408 for air, and n equals 1·25, the expression :

$$\text{Heat added} = \text{Work done} \times \frac{Y - n}{Y - 1}$$

may be used.

Air Distribution.—When designing transmission lines from the compressor or receiver to the point of distribution, it is advisable to keep the velocity of the air in the pipes to below 40 ft. per sec., for as the friction losses between the air and the pipe vary directly as the length of duct, directly as the square of the velocity, and inversely as the diameter—it can be seen that a pipe-line must be designed within reasonable limits of these considerations.

It is, therefore, essential that the pressure loss over a length of piping should be known in order that the correct operating pressure may be secured at the point of application ; for small pipes the friction loss may be computed from the following :

$$f = \frac{clV^2}{d^5r} \quad \text{where } c = \frac{0\cdot022d}{12}$$

$$\therefore \quad f = \frac{0\cdot002lV^2}{12d^4r},$$

where f = Loss of pressure (lb. per sq. in.).
l = Length of pipe (ft.).
V = Cubic feet of air passing per second.
d = Diameter of pipe (in.).
r = Ratio of compression (atmospheric).
c = Constant from $c = \frac{0\cdot022d}{12}$.

Where cast- or wrought-iron pipes are used for air mains the coefficient of friction may be calculated by Professor M. C. Unwin's formula, where :

Coefficient = $0\cdot0027\ (1 + 3/10d)$, and d equals the diameter of the pipe in feet.

It is advisable to reduce the number of bends or changes in direction as is consistent with the line layout, and when these have to be employed to use long sweep bends wherever possible.

It will be appreciated how necessary it is that the air for engineering and industrial purposes should be free from impurities. These are not solely impurities of the air itself before compression, but include water which results from the

compression of the aqueous vapour in the air, oil which the air picks up in its passage through the compressor, and scale and rust that inevitably form in the delivery pipe. The quality of filtration necessary varies with the applications; for example, if the air is to be used to support life in tunnelling operations or for food manufacture, it must be absolutely free from impurities. If used for pneumatic tools, it should be free from dust, scale, and moisture, but the oil carried over is not detrimental.

It will be realised that filtration of the compressed air must be as near the point of application as possible—the ideal being a filter for the air before it enters the compressor, a pipe-line filter on the outlet side of the receiver and one or more along the length of pipe-line, depending upon its length and the presence of bends and pipe reductions. There should, of course, be one at the point of application of the compressed air.

The first filter picks up the dust and dirt, and so prevents wear in the compressor (of which 80 per cent. is directly attributable to atmospheric dust), and the others remove the water, scale, and rust which result from compression and delivery through iron pipes, and the oil.

The life of drills and air tools generally used in mining, roadmaking, excavation, workshops, etc., is seriously affected by dust if the compressed air is not filtered. This is particularly so in a dry and dusty atmosphere.

In moist atmospheres, such as are experienced in temperate climates, water vapour in the air is a troublesome factor, not only in producing rust but, due to compression and subsequent expansion, ice forms in the pipe tools, which results in jamming. After-coolers to a very large extent alleviate this trouble, but in all cases it is advisable to fit pipe-line filters.

Uses of Compressed Air.—The uses of compressed air for engineering and industrial purposes are manifold, for not only is it applied to engineering purposes, such as power hammers, presses, hand tools, clamps, rock and road drills, etc., but the more recent developments in turbo compressors have extended the field to the pneumatic conveying of such materials as grain, ashes, gravel, chemicals, etc., also for the supercharging and blowing for scavenging of large oil-engines, agitation for flotation processes in the production of ores, copper, etc. Compressed air is extensively used for the ventilation and cooling of mines and tunnels, while developments in aeronautical production have led to the use of compressed air for the operation of wind tunnels used for aerodynamic research, and a wide range of small pneumatic tools such as chipping and caulking hammers, riveting hammers, screwdrivers, nut runners, shearing machines, grinders, drills, etc.

The introduction of small pneumatic hand tools has been facilitated by the development of the rotary vane-type motor, which gives the maximum horse-power per pound of weight.

The vanes of this are usually constructed of special Bakelite composition; drive to the driven member through the rotor shaft is by epicyclic gearing; while all gears and rotating parts are manufactured from chrome-nickel-molybdenum steel, hardened and tempered, with every bearing of the ball or roller type, so that, apart from lubrication, servicing is reduced to the barest minimum.

Pneumatic squeeze riveters are now being extensively employed for fabricating components, especially when the De Bergue type and "dimple" riveting are used. One type of squeeze riveter suitable for closing full cup-head duralumin rivets up to $\frac{3}{16}$-in. diameter is made in three sizes with cylinders 6-in., 9-in., and 12-in. diameter respectively, with a large selection of special yokes of varying reach and clearance. The machine consists of a piston and cylinder mounted on the yoke, with the moving snap-head carried in the end of the piston rod. Operation is by foot-operated valve, leaving the operator with both hands free to manipulate the component being worked.

Compressed air is used extensively for raising water from boreholes and in pumping liquids from a lower to a higher level in food- and chemical-manufacturing processes.

Advantages of this method of pumping are that the machinery may be situated a distance away from the point of application, or a number of vats holding liquids may be emptied from one central plant provided that the necessary pressure is available.

Approximate proportions for an airlift pump are :
Air pressure pounds per square inch = $\frac{3}{10}$ depth to inlet.
Cubic feet per minute per 1000 gallons pumped per hour = $\frac{1}{3}$ air pressure in lb.

$$\text{Diameter of delivery pipe} = \sqrt[3]{\frac{\text{galls. per hour}}{100}}.$$

$$\text{Diameter of air-pipe} = \sqrt{\frac{\text{galls. per hour}}{75}}.$$

$$\text{or } V = \frac{LG}{1100P}$$

where V = Volume of free air per minute.
L = Total lift in feet.
G = Gallons lifted per minute.
P = I.H.P. per cubic foot free air compressed isothermically to a pressure equal to the submergence, i.e. 0·155 for a single-acting compressor at 60 lb. ; 0·225 for a double-acting compressor at 60 lb.

Turbo Blowers are used where very large quantities of air at low pressure are required, such as for blast furnaces, glass blowing, cement manufacture, etc. They are similar in construction to a turbo compressor but whereas the blower supplies large volumes at pressures up to and around 10 lb. per sq. in., the turbo compressor delivers a smaller quantity at pressures up to and round 100 lb. per sq. in.

The casing is built up of a series of sections, so that the number of compression stages may vary ; as well as being split horizontally for accessibility to the rotor. Diffusers are cast integral with the casing units and are of the discharge-vane type.

The impellers are of the axial-inlet radial-flow type, constructed of aluminium alloy and fixed to a steel shaft, being balanced both statically and dynamically.

Sealing rings are fitted between stages, and the rotor runs on ball or roller bearings. Control of this type of machine is by butterfly valve and by electrical gear.

Air Consumption of Pneumatic Tools.—The following gives approximately the consumption of air at 100 lb. per sq. in. for some of the more widely used tools :

Riveting Hammers	
For $\frac{7}{8}$-in. rivets	20 cu. ft. per min.
Heavy riveting hammer	30 cu. ft. per min.
Breast drill, $\frac{5}{8}$-in. diam.	18 cu. ft. per min.
Pillar Drill	
$2\frac{1}{2}$-in. diam.	35 cu. ft. per min.
Tapping Drill	
Heavy	50 cu. ft. per min.
Large Drill	
Road, etc.	200 cu. ft. per min.

PLANING AND SHAPING

Planing Machines.—Planing machines and shapers are used for producing flat surfaces on metal, for T-slotting and similar work. The difference between the two is that the planer is used for work that is too large for the shaper to handle. In most types of planer (except in the case of edge planers) the work is secured to a moving table, the tool being stationary and held in tool-holders, the feed being at right angles to the direction of movement of the table. Shapers work on the opposite principle, i.e. the work is held stationary while the tool moves in order to make the cut.

In the case of edge planers, which are used for truing up the edges of large plates, the principle is the same as in the shaper, i.e. the tool carriage moves to take the cut while the work is held stationary. One form of planer consists of a table with two vee slides fitting in grooves in the top of the bed and having two standards supporting a cross bar.

To this a saddle is fitted carrying a tool holder and slide; the saddle can be moved in either direction by hand or can be moved automatically through the medium of a square-threaded screw. The tool itself can be fed up or down by hand or automatically, and the feed can be altered, if necessary, while the machine is actually in operation.

Two pulleys of different diameters operating through a rack-and-pinion arrangement cause the table to move, one of the pulleys at the same time giving a rapid return stroke. The length of the stroke is regulated by adjustable tappets, bolted to the tee-shaped slots in the side of the table, which strike a lever as the table moves, operating the belt-shifting gear.

High-speed Planers.—The high-speed type of planing machine is capable of giving best results only with modern high-speed tools, and it differs from the ordinary type of planer in many important ways. The bed of a high-speed planing machine is of great strength and depth, braced strongly with cross girths of box-girder section, and the vee slides are automatically lubricated. The table also is very deep and well reinforced underneath, and in this case the tee slots are cut from the solid.

The heads are graduated for swivelling and have automatic feeds in all directions. A motor of constant speed can be used for direct driving, and this is mounted on the top of the machine and always runs in one direction. A variable-speed drive (which may be self-contained or otherwise, according to the particular design) allows of the following speeds:

On sizes above 48 in. the cutting speeds provided are 30 ft., 40 ft., and 50 ft. per min., with a constant return speed of 65 ft. per min.

On sizes below 48 in. the cutting speeds are 30 ft., 40 ft., 50 ft., and 60 ft. per min., with a return speed varying from 90 ft. to 140 ft. per min., according to the size of the machine. Belt drive is utilised in order to ensure lack of vibration, which might result from badly running gears.

The size and form of the work-piece to be planed decides the method of holding the work in the machine. Small work can be held in one or more vices, but if the work is heavy and large it can be secured directly to the table by means of plates and bolts, utilising the tee-shaped slots and holes provided for the purpose.

According to the shape and form of the work it is necessary to make use of devices such as angle-plates, levelling wedges, parallel packing, stopping plates, hardwood blocks, etc., to ensure that the work is held rigidly to the correct setting.

The Action of the Shaper.—The action is as follows. As the driving disc carrying the crankpin revolves, the die block mounted upon it slides along the ways in the swinging link, hence the extreme positions of movement of the swinging link do not occur when the crankpin is on the centre line; and so the stroke made while the crank is traversing the upper portion of its movement takes longer than the stroke made during its lower portion of travel whilst the crank travels at constant angular velocity. Another feature of this motion is that the forward movement has a longer period of approximately even linear velocity to the ram than could be obtained by use of a crank and connecting rod of normal steam-engine type, owing to the fact that the leverage of the swinging link is greater at the ends of the stroke than at the middle part of it.

The stroke of this mechanism can be adjusted by means of a shaft which drives, through bevel gears, a lead screw which traverses the crankpin along a radial slot. Owing to this stroke-adjustment feature, the length of stroke in use must be taken into account when setting the speed of a mechanically driven shaper, as the cutting speed depends upon the combination of strokes per minute and stroke length. This consideration does not, of course, apply to hydraulically driven shaping machines, as with this type of drive to the ram the speed adjustment varies the linear cutting speed, and the stroke is adjusted by the position of stops mounted on the ram and engaging a trip dog at each end of the stroke, and so not affecting the cutting speed; whereas with stroke adjustment, although the speed of the crank is not changed, the cutting speed is increased.

The ram is driven back and forth across the work table; the bed has vertical adjustment and has a cross motion or feed. The combined effect of cross motion and the to-and-fro action of the cutting tool is the production of a flat surface.

By means of adjustment to the tool slide carried upon the ram, angular faces

can be machined; and by manipulation of the two feeds (vertical and horizontal), profiles can be formed.

When designing work-holding fixtures for use on the shaper, consideration must be given to the cutting thrusts encountered, which tend to slide the work-piece along the bed and also to lift the end at the commencement of the stroke.

Owing to the fact that the shaping machine uses single-point tools of a similar form to those used on the lathe, it is useful for first operations on castings and short runs.

Machining Long Bars.—A frequent problem is that of machining operation which requires the stroke to take place along a lengthy bar. Some shaping machines are built with a "Y"-shaped upper end to the swinging member of the drive mechanism and a channel-shaft connecting link. This simplifies the matter considerably, but when this feature is absent the bar can be mounted so that it is alongside the shaper and the provision of a special tool holder is made.

Machining Keyways.—Internal keyways present a problem which can be easily overcome by means of an extension holder. The use of this holder is greatly increased by the fitting of a specially constructed angle plate with T slots in its face and a clearance hole provided with "nest rings." Such a fitment enables gears, pulleys, etc., to be mounted on the angle plate with ample support to the boss, which will take the maximum cutting thrust and is readily accessible to the special extension tool holder.

A steadier cut is obtained if the "clapper" is bolted down and hand feed is applied to the vertical slide during the short period that the tool is out of the bore.

Such an arrangement is helpful in a tool room for machining die openings, especially with the addition of a revolving table to enable the work to be tilted and so to allow of the profiling of the hole.

Machining Dovetail Slides.—Difficulty is experienced when machining dovetail slides owing to the tool "digging in" on the return stroke and so spoiling the work and breaking the tool. There are several methods of overcoming this trouble. The simplest is to securely bolt down the clapper of the tool slide. When using this method, the stroke should be set somewhat longer than is required in order to enable the operator to apply the angular feed during the period that the tool is away from the work-piece before commencing the cutting stroke. This method, although so simple, is not free from trouble. Owing to the intense rubbing action of the tool on the return stroke, tool wear is great; also the operator must be careful to feed at exactly the correct moment or tool chipping and breakage will result. Another method is to fit a spring-steel blade behind the tool so that on the forward stroke the spring is deflected but on the return stroke the spring catches the work-piece and lifts the tool clear.

The best method, although the most expensive, is to fit a tool-lifting attachment on the machine itself.

The swivel pin of the clapper is replaced by a longer one fixed to the clapper and pivoting in the tool box, and to this pin is fitted a friction disc pressed against a gear wheel by a spring. A rack engages with the gear, and it is fixed to a pivot pin on the machine body and slides through a swivel box on the clapper pin, which keeps the rack in engagement with the gear wheel.

With this attachment the clapper is positively raised during the return stroke and is held down during the cutting stroke.

Graduating Scales.—Another application is that of the graduation of small scales when a dividing machine is not available. A new feed ratchet wheel is made with a number of teeth to suit the divisions required. A sharp vee tool is placed in the tool holder, and the feed so arranged that although only one tooth of the feed ratchet is advanced per stroke the pawl nearly rides over the second tooth. This results in a lull in the feed during the return stroke of sufficient length to allow the tool to be completely withdrawn from the work-piece before the feed commences. This is essential, as it ensures clean graduations and saves the delicate marking tool from chipping due to side thrusts which would be present if the feed commenced while the tool was still in the groove made during the forward stroke.

The scales are placed in a small fixture. A simple stop is provided for the cross slide, so that the initial position of the slide is determined.

When the shaper is set running, the scale is automatically graduated.

DRILLS AND DRILLING

To get the maximum efficiency and full life of a properly made and tempered drill, the first requisite is that it be properly ground at the point. This means that both cutting edges should have (*a*) the same inclination to the axis of the drill, (*b*) exactly the same length, as shown in Fig. 1, and (*c*) proper clearance. Experience has shown that 12 degrees (see Fig. 2) is the best angle at the periphery of the drill. This angle should be increased gradually, as the centre of the drill is approached, and when the point is correctly ground, the line across the centre of the web stands at an angle of approximately 135 degrees with the cutting edges, as shown in Fig. 3. The failure to give sufficient angle of lip clearance at the centre of the drill is the principal cause of splitting drills up the web. When the point is central but the angles of the cutting edges different, the drill will bind on the side of the hole opposite to the lip which is cutting. It will drill too large a hole and all the work will fall on the one cutting edge. Fig. 4 illustrates this condition. When the point is ground with equal angles but with cutting edges of different lengths, the point will no longer be central and the condition shown in Fig. 5 will result. When both angle and length of cutting edges are wrong, the drill will be labouring under the severe conditions shown in Fig. 6.

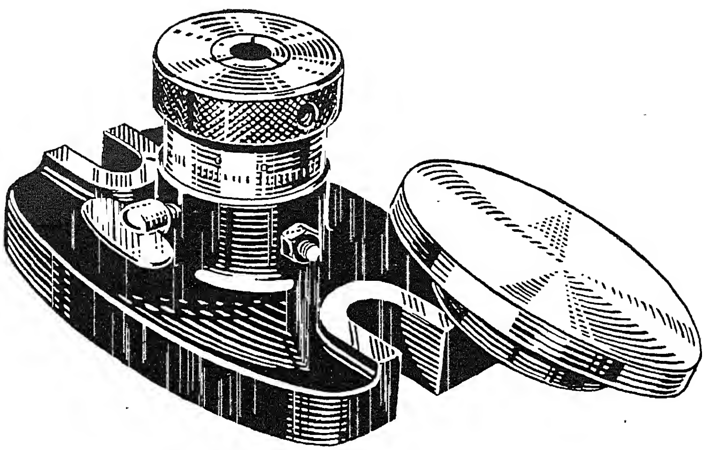
Drilling Speeds and Feeds.—The subject of the speed at which a drill should run and the feed per revolution is one upon which no hard-and-fast rule can be given. The composition and hardness of material, depth of hole, lubricant, type of machine used, condition of machine, set-up, point grinding, quality of holes desired, and many other items have a distinct influence in the determination of the best and most economical speed and feed to use for any particular job. It should be remembered that the following speeds and feeds are merely suggestions, and that it is possible to find many jobs that must be run under entirely different conditions. The correct speeds and feeds should be determined by good, sound judgment and trial in each separate case. See also *Speeds and Feeds*, pages 633 to 651.

SUGGESTED SPEEDS FOR HIGH-SPEED DRILLS

	Speed in f.p.m.
Mild machinery steel 0·2 to 0·3 per cent. C	80–110
Steel 0·4 to 0·5 per cent. C	70– 80
Tool steel 1·2 per cent. C	50– 60
Steel forgings	50– 60
Alloy steel	50– 70
Stainless steel	30– 40
Soft cast iron	100–150
Hard chilled cast iron	70–100
Malleable iron	80– 90
Ordinary brass and bronze	200–300
High-tensile bronze	70–150
Monel metal	40– 50
Slate, marble, and stone	15– 25
Aluminium and its alloys	200–300
Magnesium and its alloys	250–400
Bakelite	100–150
Wood	300–400

Carbon drills should be run at speeds of from 40 to 50 per cent. of those given above.

Feeds.—Feeds are governed by the size of the drill and the material drilled. The general rule is to use a feed of 0·001 to 0·002 in. per revolution for drills smaller than $\frac{1}{8}$ in., 0·002 to 0·004 for drills $\frac{1}{8}$ to $\frac{1}{4}$ in., 0·004 to 0·007 for drills $\frac{1}{4}$ to $\frac{1}{2}$ in., 0·007 to 0·015 for drills $\frac{1}{2}$ to 1 in., and 0·015 to 0·025 for drills larger than 1 in.



Alloy and hard steels should generally be drilled at a lighter feed than given on p. 1094, while cast iron, brass, and aluminium may usually be drilled with a heavier feed than given on p. 1094.

A drill split up the web is evidence of too much feed or insufficient lip clearance at the centre due to improper grinding. The rapid wearing away of the extreme outer corners of the cutting edges indicates that the speed is too high. The best results will be obtained when the effect of the work on the tool is somewhere between the above conditions. A drill chipping or breaking out at the cutting edges indicates that either the feed is too heavy or the drill has been ground with too much lip clearance.

Lubricants.—To maintain the speeds and feeds recommended above it will be necessary to use a good cutting compound, and the following are recommended in the order named (see also *Cutting Compounds*, p. 353):

Hard and refractory steel—turpentine, kerosene, soluble oil.

Soft steel and wrought iron—lard oil, soluble oil.

Malleable iron—soluble oil.

Brass—dry.

Aluminium and soft alloys—kerosene, soluble oil.

Cast iron—dry or with a jet of compressed air for a cooling medium.

The above recommendations for lubricants apply equally well to carbon or high-speed drills.

A drill tempered to give maximum results drilling hard steel might be too brittle to work well in softer and tougher materials. The commercial twist drill is tempered for average conditions to give good results in either hard or soft material. Variations in the hardness of the material drilled should, of course, be met by the skilled operator with changes in the speed and feed. Insufficient speed in drilling small holes with hand feed greatly increases the risk of breakage, especially at the moment the point of the drill is breaking through the farther side of the work. This is due to the operator's inability to correctly gauge the feed when the drills are running too slow.

Drilling with Automatic Machines.—High speeds and light feeds are especially recommended for automatic machines where holes do not exceed four diameters of the drill in depth. For holes deeper than four diameters an oil-hole or oil-tube drill will often be found advantageous.

Nothing will check a high-speed drill quicker than to turn a stream of cold water on to it after it has become heated working in a hole. It is equally bad to plunge it into cold water after the point has been heated in grinding. The small checks or cracks resulting from the above practice will eventually chip out and cause rapid wear or breakage.

Drills that are properly hardened and pointed and run at moderate speeds and feeds are often condemned on account of breakage when the trouble rightly should be charged to the drilling machine. If there is any spring or play between the upper part of the machine and the table, the drill will not begin to cut until the feed-pressure has taken this up, after which the feed will be practically constant until the point of the drill breaks through. When this happens, the resistance to the penetration of the drill is abruptly reduced and it "hogs in." This causes a great increase in torsional strain, which frequently breaks the drill. Any movement of the table with reference to the upper part of the machine while drilling a hole throws the spindle out of alignment with the hole and bends or cramps the drill, which often causes it to break.

Tangs.—The tang exists to assist the taper shank in driving the tool. It is not designed to withstand the entire driving strain. Under ideal conditions no tang would be necessary, as a perfect fit between the taper shank and the hole in the spindle would, in itself, give a sufficient drive. When the parts are badly worn, or proper care has not been taken to keep the taper surfaces free from grit, the driving function of the taper fit is lost and an undue strain is thrown upon the tang. Under such conditions is it any wonder that occasionally the tang proves unequal to this additional burden and is twisted off?

If, however, the taper surfaces are kept clean and the driving part in perfect condition, the tang will be required to perform only its legitimate function and the greater part of the trouble experienced from broken and twisted tangs will be eliminated.

Drilling Speed Table

This table may be used in preference to that on page 640 when high-speed drills are used.

Diameter Drill	*Feed per. Rev.*	30	40	50	60	70	80	90	100	110	120	130	140
		Peripheral Speed in Feet per Minute											
in.	*in.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*	*r.p.m.*
$\frac{1}{32}$	0·001	3668	4888	6112	7336	8560	9776	11008	12224	13448	14672	—	—
$\frac{1}{16}$	0·0015	1834	2444	3056	3668	4280	4888	5504	6112	6724	7336	7944	8556
$\frac{3}{32}$	0·002	1222	1620	2040	2444	2853	3260	3668	4076	4484	4888	5292	5700
$\frac{1}{8}$	0·0025	917	1222	1528	1834	2140	2444	2752	3056	3362	3668	3972	4278
$\frac{5}{32}$	0·003	735	980	1222	1470	1712	1955	2200	2444	2690	2932	3178	3422
$\frac{3}{16}$	0·004	610	810	1020	1222	1426	1630	1834	2038	2242	2444	2646	2850
$\frac{7}{32}$	0·005	524	700	874	1050	1222	1396	1572	1748	1920	2098	2272	2448
$\frac{1}{4}$	0·005	460	610	764	920	1070	1222	1376	1528	1681	1834	1986	2139
$\frac{9}{32}$	0·006	400	540	678	810	951	1086	1222	1358	1494	1626	1766	1902
$\frac{5}{16}$	0·006	367	490	610	730	856	978	1100	1222	1344	1466	1589	1711
$\frac{11}{32}$	0·0065	334	444	555	666	778	888	1000	1110	1222	1332	1444	1540
$\frac{3}{8}$	0·0065	306	405	509	610	713	815	916	1018	1121	1222	1323	1425
$\frac{7}{16}$	0·007	262	350	437	525	610	700	786	874	960	1050	1136	1224
$\frac{1}{2}$	0·008	230	306	382	460	535	610	688	764	840	917	993	1070
$\frac{9}{16}$	0·009	204	272	340	405	475	543	610	679	747	813	883	950
$\frac{5}{8}$	0·010	183	244	306	367	428	489	552	610	673	736	796	857
$\frac{11}{16}$	0·011	167	222	273	333	389	444	500	555	610	666	722	770
$\frac{3}{4}$	0·012	153	203	255	306	357	408	458	508	559	610	660	710
$\frac{13}{16}$	0·012	142	190	237	284	332	379	427	474	521	569	616	664
$\frac{7}{8}$	0·013	131	175	218	262	306	350	390	438	482	526	569	612
$\frac{15}{16}$	0·013	122	163	204	244	285	326	366	406	448	488	530	570
1	0·013	115	153	191	230	267	306	344	382	420	458	497	535
$1\frac{1}{8}$	0·014	102	136	170	204	238	272	306	340	374	408	442	476
$1\frac{1}{4}$	0·014	92	122	153	183	214	245	274	306	337	367	398	428
$1\frac{3}{8}$	0·015	83	110	139	167	195	222	250	278	306	334	360	390
$1\frac{1}{2}$	0·015	76	102	127	153	178	204	230	254	279	306	330	356
$1\frac{5}{8}$	0·015	70	94	117	140	165	188	212	234	257	280	306	328
$1\frac{3}{4}$	0·015	65	87	109	130	153	175	196	218	240	262	283	306
$1\frac{7}{8}$	0·015	61	80	102	122	143	163	184	204	224	244	265	286
2	0·016	57	76	95	115	134	153	172	190	210	229	248	267
$2\frac{1}{4}$	0·016	51	68	85	102	119	136	153	170	187	204	220	238
$2\frac{1}{2}$	0·016	46	60	76	92	107	122	138	153	168	184	200	213
$2\frac{3}{4}$	0·016	42	56	70	83	97	111	125	139	153	167	181	195
3	0·016	38	50	63	76	89	102	114	127	140	152	165	178

These speeds and feeds are only approximate and can be used only as a general guide, as much depends on class of work, depth of hole, and condition of machine.

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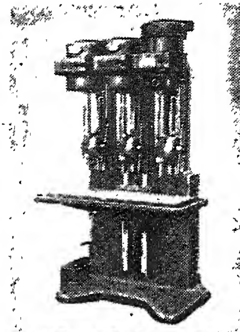

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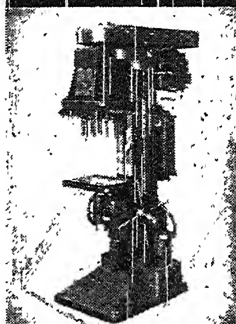

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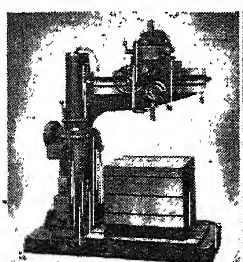
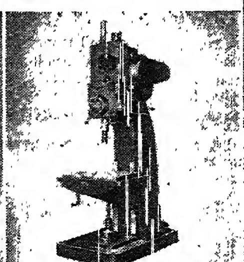
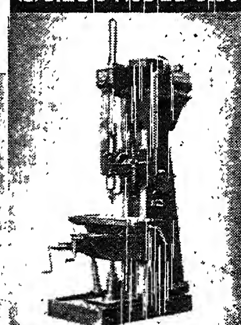


(5) TYPE 'SV' MODEL 140



(4) TYPE 'G' MODEL 6300



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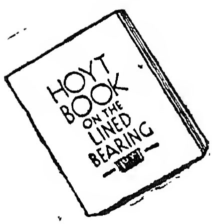

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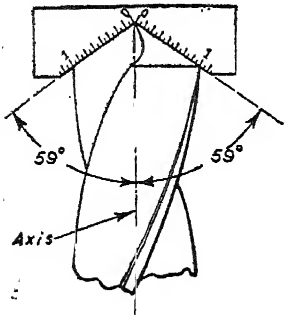
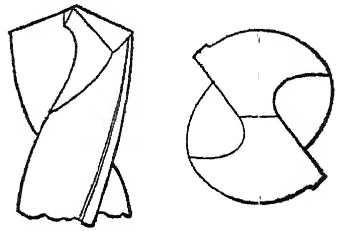


Fig. 1.—Correctly ground lips. The two lips of this drill are of the same length and make the same angle to the axis of the drill.



Figs. 7 and 8.—Showing what is known as notched-point thinning.

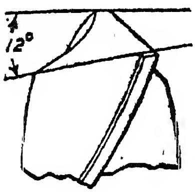


Fig. 2.—Showing the proper way to grind back the surface of the cutting lip. The angle indicated is the angle at the circumference of the drill.

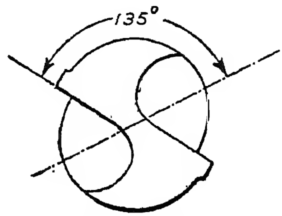


Fig. 3.—When the point is correctly ground the line across the centre of the web makes an angle of approximately 135 degrees with the cutting edges.

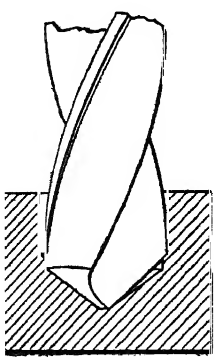


Fig. 4.—Incorrectly ground lips. The angles of the two lips are different. As a result the cutting edge on the left is doing most of the work while the one on the right is removing only a small portion of the metal. Note that the hole is larger than the drill.

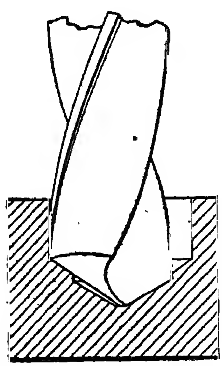


Fig. 5.—Incorrectly ground lips. The angles of the lips are equal, but their lengths are different. Here again the hole is much larger than the drill and the punishment to the tool is terrific.

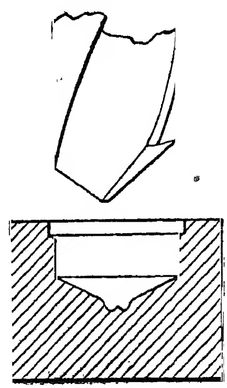


Fig. 6.—Incorrectly ground lips. The angles of the lips are unequal and the lips are of different lengths. Note the effect on the hole.

Drilling in Hard Material.—The drilling of hard material is facilitated by using turpentine as a cutting compound, and in the case of very hard material by grinding off the sharp angles of the cutting edges, equally on both sides, so as to permit the use of heavy feeds without chipping the cutting edges. This must be done with extreme care and good judgment, however, or the drill will be unfitted for further use. The form of point will also be found efficient in drilling soft material, like brass, where the regular point has a tendency to "hog in" or "grab."

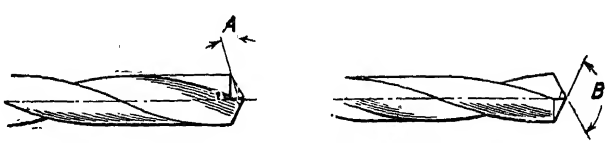
Maximum results so far as ease of penetration and wear are concerned may best be obtained by thinning the web as the drill is worn back. This operation may be done in several ways. In one the thinning is done with a round-faced emery wheel.

Fig. 7 and Fig. 8 illustrate what is known as the notched-point thinning, and is done with a sharp-cornered hard emery wheel. This type of thinning is especially adapted for hand feed, such as crankshaft drilling, turret lathe, screw machine, and similar work.

Cutting Ability.—A fact often lost sight of, even by experienced users of drills, is that cutting ability and hardness are not the same thing. This is especially true of high-speed drills, the apparent hardness of which varies with the composition and heat treatment of the steel and is no indication of the cutting ability. Some of the best high-speed tools can be filed very readily. A high-speed drill that cannot be filed may, by exercising the greatest care, be made to drill extremely hard material successfully; but for softer materials, or where a large amount of work must be done in a minimum time, it will be found so brittle as to be unsatisfactory. Numerous tests have proved that the cutting ability of files varies quite as much as that of other hardened tools, and this is another reason why file tests are unreliable. No drill that files hard or soft should be condemned for that reason alone, but should first be given a drilling test in material of known hardness.

Web Thickness.—As the centre web of a drill increases in thickness towards the shank, it is desirable to periodically thin it for a short distance back from the point, which should be maintained central and of the same thickness as when new. In the case of taper-shank drills, these should be used in properly fitting sockets free from bruises, dirt, or chips. With straight-shank drills see that a really high-class chuck is used. A slipping chuck with an automatic feed on the machine will break the drill. When deep drilling with special-length drills, withdraw the drill frequently so as to clear the chips which may bind in the flutes. Maintain drilling machines free from backlash in spindle and thrust bearings, and also locate work firmly and securely on the machine table.

Drilling Square Holes.—There are many methods of drilling square holes, although it is impossible to drill a square hole with sharp corners. The practical method is to broach the hole or to drift it. Drilling is sometimes resorted to when the hole is blind ended. The usual method when special drilling attachments are not available is to make a jig plate in which is pierced a square hole identical in dimensions with the size of hole required. The plate should be at least $\frac{7}{8}$ in. thick for holes up to $\frac{5}{8}$ in. square. For holes of larger size the thickness must be not less than one and a half times the side of the square. A suitable cylindrical bush is placed in the square hole of the jig, and a drill is fed through. The bush is then removed and the square-hole drill substituted and fed through. The drill is mounted in a floating drill chuck. The square-hole drill is of triangular form and has three cutting edges at the bottom. The same principle can, of course, be adopted for drilling hexagonal holes, as well as other shapes. Such drills are made by Helsby Barnes Ltd.



Diagrams relating to table on p. 1099.

Drill Angles for Soft Materials

(*See diagrams on page* 1098)

Material	*Side* "*A*"	*Point* "*B*"	*Spiral* 7/16	*Remarks*	
Electron	15°	100°	15°	Boiler work web Standard lengths Point thinned	
Alpax (aluminium-silicon alloy) ..	14°	140°	45°	Boiler work web Standard lengths Point thinned Wider grooves than standard	
Duralumin, Aluminium ..	14°	140°	45°	Boiler work web Standard lengths Point thinned	
Copper	14°	125°	45°		
Brass	15°	130°	10°	Boiler work web Standard lengths Point thinned	
Manganese ..	10°	125°	12½°	50 per cent. on boiler work web ¾ of standard lengths Point thinned Narrow lands	
Stainless	15°	100°	Std.	50 per cent. on boiler work web ¾ of standard length Pint thinned	
Bakelite, Vulcanite ..	5°	30°	20°	Standard web Standard lengths Wide flutes Narrow lands	
Gummoid, Hard Pertinax, Rubber, Hardpaper, Galalith .., Celluloid ..	8°	65°	15°	As for Bakelite	
Marble	5°	80°	15°	Boiler work web Standard lengths	
Wood	15°	180°	45°	Boiler work web Standard lengths	
Slate	7°	Std.	45°	100 per cent. boiler work web Standard lengths	
Bullet-proof Plate	7°	120°	17½°	50 per cent. standard web ¾ of standard length Point thinned	
BMG, Monel	14°	125° 130°	25°/35°	10 per cent. on standard web Standard lengths Point thinned	
Manganese Bronze	12°	130°	12°	50 per cent. on boiler work web ¾ of standard length Point thinned	

Decimal Equivalents of Standard Drill Sizes

In.	*No.*	*Mm.*	*Decimal*	*In*	*No.*	*Mm.*	*Decimal*
—	80	—	0·0135	—	—	1·60	0·0630
—	—	0·35	0·0138	—	52	—	0·0635
—	79	—	0·0145	—	—	1·65	0·0650
$\frac{1}{64}$	—	—	0·0156	—	—	1·70	0·0669
—	—	0·40	0·0158	—	51	—	0·0670
—	78	—	0·0160	—	—	1·75	0·0689
—	—	0·45	0·0177	—	50	—	0·0700
—	77	—	0·0180	—	—	1·80	0·0709
—	—	0·50	0·0197	—	—	1·85	0·0728
—	76	—	0·0200	—	49	—	0·0730
—	75	—	0·0210	—	—	1·90	0·0750
—	—	0·55	0·0217	—	48	—	0·0760
—	74	—	0·0225	—	—	1·95	0·0768
—	—	0·60	0·0236	$\frac{5}{64}$	—	—	0·0781
—	73	—	0·0240	—	47	—	0·0785
—	72	—	0·0250	—	—	2·00	0·0787
—	—	0·65	0·0256	—	—	2·05	0·0807
—	71	—	0·0260	—	46	—	0·0810
—	—	0·70	0·0276	—	45	—	0·0820
—	70	—	0·0280	—	—	2·10	0·0827
—	69	—	0·0293	—	—	2·15	0·0847
—	—	0·75	0·0295	—	44	—	0·0860
—	68	—	0·0310	—	—	2·20	0·0866
$\frac{1}{32}$	—	—	0·0313	—	—	2·25	0·0886
—	—	0·80	0·0315	—	43	—	0·0890
—	67	—	0·0320	—	—	2·30	0·0906
—	66	—	0·0330	—	—	2·35	0·0925
—	—	0·85	0·0335	—	42	—	0·0935
—	65	—	0·0350	$\frac{3}{32}$	—	—	0·0938
—	—	0·90	0·0354	—	—	2·40	0·0945
—	64	—	0·0360	—	41	—	0·0960
—	63	—	0·0370	—	—	2·45	0·0965
—	—	0·95	0·0374	—	40	—	0·0980
—	62	—	0·0380	—	—	2·50	0·0984
—	61	—	0·0390	—	39	—	0·0995
—	—	1·00	0·0394	—	—	2·55	0·1004
—	60	—	0·0400	—	38	—	0·1015
—	59	—	0·0410	—	—	2·60	0·1024
—	—	1·05	0·0413	—	37	—	0·1040
—	58	—	0·0420	—	—	2·65	0·1043
—	57	—	0·0430	—	—	2·70	0·1063
—	—	1·10	0·0433	—	36	—	0·1065
—	—	1·15	0·0453	—	—	2·75	0·1083
—	56	—	0·0465	$\frac{7}{64}$	—	—	0·1094
$\frac{3}{64}$	—	—	0·0469	—	35	—	0·1100
—	—	1·28	0·0472	—	—	2·80	0 1102
—	—	1·25	0·0492	—	34	—	0·1110
—	—	1·30	0·0512	—	—	2·85	0·1122
—	55	—	0·0520	—	33	—	0·1130
—	—	1·35	0 0532	—	—	2 90	0·1142
—	54	—	0·0550	—	32	—	0·1160
—	—	1·40	0·0551	—	—	2·95	0·1161
—	—	1·45	0·0571	—	—	3 00	0·1181
—	—	1 50	0·0591	—	31	—	0·1200
—	53	—	0·0595	—	—	3·10	0·1221
—	—	1·55	0·0610	$\frac{1}{8}$	—	—	0·1250
$\frac{1}{16}$	—	—	0·0625	—	—	3·20	0·1260

Decimal Equivalents of Standard Drill Sizes—*continued*

In.	*No.*	*Mm.*	*Decimal*	*In.*	*No.*	*Mm.*	*Decimal*
—	30	—	0·1285	—	—	5·60	0·2205
—	—	3·30	0·1299	—	2	—	0·2210
—	—	3·40	0·1339	—	—	5·70	0·2244
—	29	—	0·1360	—	1	—	0·2280
—	—	3·50	0·1378	—	—	5·80	0·2284
—	28	—	0·1405	—	—	5·90	0·2323
$\frac{9}{64}$	—	—	0·1406	—	Letter A	—	0·2340
—	—	3·60	0·1417	$\frac{15}{64}$	—	—	0·2344
—	27	—	0·1440	—	—	6·00	0·2362
—	—	3·70	0·1457	—	B	—	0·2380
—	26	—	0·1470	—	—	6·10	0·2402
—	25	—	0·1495	—	C	—	0·2420
—	—	3·80	0·1496	—	—	6·20	0·2441
—	24	—	0·1520	—	D	—	0·2460
—	—	3·90	0·1535	—	—	6·30	0·2480
—	23	—	0·1540	$\frac{1}{4}$	E	—	0·2500
$\frac{5}{32}$	—	—	0·1563	—	—	6·40	0·2520
—	22	—	0·1570	—	—	6·50	0·2559
—	—	4·00	0·1575	—	F	—	0·2570
—	21	—	0·1590	—	—	6·60	0·2598
—	20	—	0·1610	—	G	—	0·2610
—	—	4·10	0·1614	—	—	6·70	0·2638
—	—	4·20	0·1654	$\frac{17}{64}$	—	—	0·2656
—	19	—	0·1660	—	H	—	0·2660
—	—	4·30	0·1693	—	—	6·80	0·2677
—	18	—	0·1695	—	—	6·90	0·2717
$\frac{11}{64}$	—	—	0·1719	—	I	—	0·2720
—	17	—	0·1730	—	—	7·00	0·2756
—	—	4·40	0·1732	—	J	—	0·2770
—	16	—	0·1770	—	—	7·10	0·2795
—	—	4·50	0·1772	—	K	—	0·2810
—	15	—	0·1800	$\frac{9}{32}$	—	—	0·2813
—	—	4·60	0·1811	—	—	7·20	0·2835
—	14	—	0·1820	—	—	7·30	0·2874
—	13	—	0·1850	—	L	—	0·2900
—	—	4·70	0·1850	—	—	7·40	0·2913
$\frac{3}{16}$	—	—	0·1875	—	M	—	0·2950
—	—	4·80	0·1890	—	—	7·50	0·2953
—	12	—	0·1890	$\frac{19}{64}$	—	—	0·2969
—	11	—	0·1910	—	—	7·60	0·2992
—	—	4·90	0·1929	—	N	—	0·3020
—	10	—	0·1935	—	—	7·70	0·3032
—	9	—	0·1960	—	—	7·80	0·3071
—	—	5·00	0·1969	—	—	7·90	0·3110
—	8	—	0·1990	$\frac{5}{16}$	—	—	0·3125
—	—	5·10	0·2008	—	—	8·00	0·3150
—	7	—	0·2010	—	O	—	0·3160
$\frac{13}{64}$	—	—	0·2031	—	—	8·10	0·3189
—	6	—	0·2040	—	—	8·20	0·3228
—	—	5·20	0·2047	—	P	—	0·3230
—	5	—	0·2055	—	—	8·30	0·3268
—	—	5·30	0·2087	$\frac{21}{64}$	—	—	0·3281
—	4	—	0·2090	—	—	8·40	0·3307
—	—	5·40	0·2126	—	Q	—	0·3320
—	3	—	0·2130	—	—	8·50	0·3347
—	—	5·50	0·2165	—	—	8·60	0·3386
$\frac{7}{32}$	—	—	0·2186	—	R	—	0·3390

DECIMAL EQUIVALENTS OF STANDARD DRILL SIZES—*continued*

In.	*No.*	*Mm.*	*Decimal*	*In.*	*No.*	*Mm.*	*Decimal*
—	—	8·70	0·3425	—	—	9·60	0·3780
11/32	—	—	0·3438	—	—	9·70	0·3819
—	—	8·80	0·3465	—	—	9·80	0·3858
—	S	—	0·3480	—	W	—	0·3860
11/32	—	8·90	0·3504	—	—	9·90	0·3898
—	—	9·00	0·3543	25/64	—	—	0·3906
—	T	—	0·3580	—	—	10·00	0·3937
—	—	9·10	0·3583	—	X	—	0·3970
23/64	—	—	0·3594	—	—	10·10	0·3976
—	—	9·20	0·3622	—	—	10·20	0·4016
—	—	9·30	0·3661	—	Y	—	0·4040
—	U	—	0·3680	—	—	10·30	0·4055
—	—	9·40	0·3701	13/32	—	—	0·4063
—	—	9·50	0·3740	—	—	10·40	0·4095
3/8	—	—	0·3750	—	Z	—	0·4130
—	V	—	0·3770	—	—	10·50	0·4134

In.	*Mm.*	*Decimal*	*In.*	*Mm.*	*Decimal*
13/32	10·60	0·4173	37/64	—	0·5781
—	10·70	0·4213	—	15·00	0·5906
27/64	—	0·4219	19/32	—	0·5938
—	10·80	0·4252	39/64	—	0·6094
—	10·90	0·4291	—	15·50	0·6102
—	11·00	0·4331	5/8	—	0·5250
—	11·10	0·4370	—	16·00	0·6299
7/16	—	0·4375	41/64	—	0·6406
—	11·20	0·4409	—	16·50	0·6496
—	11·30	0·4449	21/32	—	0·6563
—	11·40	0·4488	—	17·00	0·6693
—	11·50	0·4528	43/64	—	0·6719
29/64	—	0·4531	11/16	—	0·6875
—	11·60	0·4567	—	17·50	0·6890
—	11·70	0·4606	45/64	—	0·7031
—	11·80	0·4646	—	18·00	0·7087
—	11·90	0·4685	23/32	—	0·7188
15/32	—	0·4688	—	18·50	0·7284
—	12·00	0·4724	47/64	—	0·7344
—	12·10	0·4764	—	19·00	0·7480
—	12·20	0·4803	3/4	—	0·7500
—	12·30	0·4843	49/64	—	0·7656
31/64	—	0·4844	—	19·50	0·7677
—	12·40	0·4882	25/32	—	0·7813
—	12·50	0·4921	—	20·00	0·7874
—	12·60	0·4961	51/64	—	0·7969
1/2	12·70	0·5000	—	20·50	0·8071
—	12·80	0·5039	13/16	—	0·8125
—	12·90	0·5079	—	21·00	0·8268
—	13·00	0·5118	53/64	—	0·8281
33/64	—	0·5156	27/32	—	0·8438
17/32	—	0·5313	27/32	21·50	0·8465
—	13·50	0·5315	55/64	—	0·8594
35/64	—	0·5469	—	22·00	0·8661
—	14·00	0·5512	7/8	—	0·8750
9/16	—	0·5625	—	22·50	0·8858
—	14·50	0·5709	57/64	—	0·8906

DECIMAL EQUIVALENTS OF STANDARD DRILL SIZES—*continued*

In.	*Mm.*	*Decimal*	*In.*	*Mm.*	*Decimal*
—	23·00	0·9055	$1\frac{25}{64}$	—	1·3906
$\frac{29}{32}$	—	0·9063	—	35·50	1·3976
$\frac{59}{64}$	—	0·9219	$1\frac{13}{32}$	—	1·4063
—	23·50	0·9252	$1\frac{13}{32}$	36·00	1·4173
$\frac{15}{16}$	—	0·9375	$1\frac{27}{64}$	—	1·4219
—	24·00	0·9449	—	36·50	1·4370
$\frac{61}{64}$	—	0·9531	$1\frac{7}{16}$	—	1·4375
—	24·50	0·9646	$1\frac{29}{64}$	—	1·4531
$\frac{31}{32}$	—	0·9688	—	37·00	1·4667
—	25·00	0·9843	$1\frac{15}{32}$	—	1·4688
$\frac{63}{64}$	—	0·9844	—	37·50	1·4764
—	—	—	$1\frac{31}{64}$	—	1·4844
1	—	1·0000	—	38·00	1·4961
—	25·50	1·0039	$1\frac{1}{2}$	—	1·5000
$1\frac{1}{64}$	—	1·0156	$1\frac{33}{64}$	—	1·5156
—	26·00	1·0236	—	38·50	1·5158
$1\frac{1}{32}$	—	1·0313	$1\frac{17}{32}$	—	1·5313
—	26·50	1·0433	—	39·00	1·5354
$1\frac{3}{64}$	—	1·0469	$1\frac{35}{64}$	—	1·5469
$1\frac{1}{16}$	—	1·0625	—	39·50	1·5651
—	27·00	1·0630	$1\frac{9}{16}$	—	1·5625
$1\frac{5}{64}$	—	1·0781	—	40·00	1·5748
—	27·50	1·0827	$1\frac{37}{64}$	—	1·5781
$1\frac{3}{32}$	—	1·0938	$1\frac{19}{32}$	—	1·5938
—	28·00	1·1024	—	40·50	1·5945
$1\frac{7}{64}$	—	1·1094	$1\frac{39}{64}$	—	1·6094
—	28·50	1·1221	—	41·00	1·6142
$1\frac{1}{8}$	—	1·1250	$1\frac{5}{8}$	—	1·6250
$1\frac{9}{64}$	—	1·1406	—	41·50	1·6339
—	29·00	1·1417	$1\frac{41}{64}$	—	1·6406
$1\frac{5}{32}$	—	1·1563	—	42·00	1·6535
—	29·50	1·1614	$1\frac{21}{32}$	—	1·6563
$1\frac{11}{64}$	—	1·1719	$1\frac{43}{64}$	—	1·6719
—	30·00	1·1811	—	42·50	1·6732
$1\frac{3}{16}$	—	1·1875	$1\frac{11}{16}$	—	1·6875
—	30·50	1·2008	—	43·00	1·6929
$1\frac{13}{64}$	—	1·2031	$1\frac{45}{64}$	—	1·7031
$1\frac{7}{32}$	—	1·2188	—	43·50	1·7126
—	31·00	1·2205	$1\frac{23}{32}$	—	1·7188
$1\frac{15}{64}$	—	1·2344	—	44·00	1·7323
—	31 50	1·2402	$1\frac{47}{64}$	—	1·7344
$1\frac{1}{4}$	—	1·2500	$1\frac{3}{4}$	—	1·7500
—	32·00	1·2598	—	44·50	1·7520
$1\frac{17}{64}$	—	1·2656	$1\frac{49}{64}$	—	1·7656
—	32·50	1·2795	—	45·00	1·7717
$1\frac{9}{32}$	—	1·2813	$1\frac{25}{32}$	—	1·7813
$1\frac{19}{64}$	—	1·2969	—	45·50	1·7913
—	33·00	1·2992	$1\frac{51}{64}$	—	1·7969
$1\frac{5}{16}$	—	1·3125	—	46·00	1·8110
—	33·50	1·3189	$1\frac{13}{16}$	—	1·8125
$1\frac{21}{64}$	—	1·3281	$1\frac{53}{64}$	—	1·8281
—	34·00	1·3386	—	46·50	1·8307
$1\frac{11}{32}$	—	1·3438	$1\frac{27}{32}$	—	1·8438
—	35·50	1·3583	—	47·00	1·8504
$1\frac{23}{64}$	—	1·3594	$1\frac{55}{64}$	—	1·8594
$1\frac{3}{8}$	—	1·3750	—	47·50	1·8701
—	35·00	1·3780	$1\frac{7}{8}$	—	1·8750

DECIMAL EQUIVALENTS OF STANDARD DRILL SIZES—*continued*

In.	*Mm.*	*Decimal*	*In.*	*Mm.*	*Decimal*
—	48·00	1·8898	—	56·50	2·2244
$1\frac{57}{64}$	—	1·8906	$2\frac{15}{64}$	—	2·2344
$1\frac{29}{32}$	—	1·9063	—	57·00	2·2441
—	48·50	1·9095	$2\frac{1}{4}$	—	2·2500
$1\frac{59}{64}$	—	1·9219	—	57·50	2·2638
—	49·00	1·9291	$2\frac{17}{64}$	—	2·2656
$1\frac{15}{16}$	—	1·9375	$2\frac{9}{32}$	—	2·2813
—	49·50	1·9488	—	58·00	2·2835
$1\frac{61}{64}$	—	1·9531	$2\frac{19}{64}$	—	2·2969
—	50·00	1·9685	—	58·50	2·3032
$1\frac{31}{32}$	—	1·9688	$2\frac{5}{16}$	—	2·3125
$1\frac{63}{64}$	—	1·9844	—	59·00	2·3228
$1\frac{63}{64}$	50·50	1·9882	$2\frac{21}{64}$	—	2·3281
2	—	2·0000	—	59·50	2·3425
—	51·00	2·0079	$2\frac{11}{32}$	—	2·3438
$2\frac{1}{64}$	—	2·0156	$2\frac{23}{64}$	—	2·3594
—	51·50	2·0276	—	60·00	2·3622
$2\frac{1}{32}$	—	2·0313	$2\frac{3}{8}$	—	2·3750
$2\frac{3}{64}$	—	2·0469	—	60·50	2·3819
—	52·00	2·0472	$2\frac{25}{64}$	—	2·3906
$2\frac{1}{16}$	—	2·0625	—	61·00	2·4016
—	52·50	2·0669	$2\frac{13}{32}$	—	2·4063
$2\frac{5}{64}$	—	2·0781	—	61·50	2·4219
—	53·00	2·0866	$2\frac{27}{64}$	—	2·4219
$2\frac{3}{32}$	—	2·0938	$2\frac{7}{16}$	—	2·4375
—	53·50	2·1063	—	62·00	2·4409
$2\frac{7}{64}$	—	2·1094	$2\frac{29}{64}$	—	2·4531
$2\frac{1}{8}$	—	2·1250	—	62·50	2·4606
—	54·00	2·1260	$2\frac{15}{32}$	—	2·4688
$2\frac{9}{64}$	—	2·1406	—	63·00	2·4803
—	54·50	2·1457	$2\frac{31}{64}$	—	2·4844
$2\frac{5}{32}$	—	2·1563	$2\frac{1}{2}$	63·50	2·5000
—	55·00	2·1654	$2\frac{33}{64}$	—	2·5156
$2\frac{11}{64}$	—	2 1719	—	64·00	2·5197
—	55·50	2·1850	$2\frac{17}{32}$	—	2·5313
$2\frac{3}{16}$	—	2·1875	—	64·50	2·5394
$2\frac{13}{64}$	—	2·2031	$2\frac{35}{64}$	—	2·5469
—	56·00	2·2047	—	65·00	2·5591
$2\frac{7}{32}$	—	2·2188			

LETTER SIZES OF DRILLS

	in.		*in.*		*in.*		*in.*		*in.*
A	0·234	G	0·261	L	0·290	Q	0·332	V	0·377
B	0·238	H	0·266	M	0·295	R	0·339	W	0·386
C	0·242	I	0·272	N	0·302	S	0·348	X	0·397
D	0·246	J	0·277	O	0·316	T	0·358	Y	0·404
E	0·250	K	0·281	P	0·323	U	0·368	Z	0·413
F	0·257								

Bit Stock Twist Drills

Taper Square Shanks $\frac{3}{8}$ in. × $\frac{7}{32}$ in. × $1\frac{1}{4}$ in. long

Diameter	*Decimal Equivalent*	*Over-all Length*	*Flute Length*
in.	*in.*	*in.*	*in.*
$\frac{1}{16}$	0·0625	$3\frac{5}{16}$	$\frac{7}{8}$
$\frac{3}{32}$	0·0938	$3\frac{5}{8}$	$1\frac{1}{4}$
$\frac{1}{8}$	0·1250	$3\frac{5}{8}$	$1\frac{3}{4}$
$\frac{5}{32}$	0·1563	$3\frac{15}{16}$	2
$\frac{3}{16}$	0·1875	$4\frac{5}{16}$	$2\frac{5}{16}$
$\frac{7}{32}$	0·2188	$4\frac{11}{16}$	$2\frac{5}{8}$
$\frac{1}{4}$	0·2500	$5\frac{3}{16}$	$3\frac{3}{16}$
$\frac{9}{32}$	0·2813	$5\frac{3}{8}$	$3\frac{3}{8}$
$\frac{5}{16}$	0·3125	$5\frac{1}{2}$	$3\frac{1}{2}$
$\frac{11}{32}$	0·3438	$5\frac{7}{8}$	$3\frac{7}{8}$
$\frac{3}{8}$	0·3750	$5\frac{7}{8}$	$3\frac{7}{8}$
$\frac{13}{32}$	0·4063	$5\frac{7}{8}$	$3\frac{7}{8}$
$\frac{7}{16}$	0·4375	$6\frac{1}{4}$	4
$\frac{15}{32}$	0·4688	$6\frac{5}{8}$	$4\frac{3}{8}$
$\frac{1}{2}$	0·5000	$6\frac{3}{4}$	$4\frac{7}{16}$
$\frac{9}{16}$	0·5625	$7\frac{1}{2}$	$5\frac{3}{16}$

Whitworth Threads

	in.	*in.*	*in.*	*in.*	*in.*
Diameter . .	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$
Tapping size .	$\frac{3}{32}$	No. 31	$\frac{9}{64}$	$\frac{3}{16}$	Letter D
Clearing size .	$\frac{9}{64}$	$\frac{11}{64}$	$\frac{13}{64}$	$\frac{17}{64}$	$\frac{21}{64}$

B.S.F. Threads

	in.	*in.*	*in.*	*in.*
Diameter	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{3}{8}$
Tapping size . . .	No. 5	Letter B	Letter G	Letter O
Clearing size . . .	$\frac{17}{64}$	$\frac{19}{64}$	$\frac{21}{64}$	$\frac{25}{64}$

B.A. Threads

Diameter .	0	1	2	3	4	5	6	7	8
Tapping size	No. 10	No. 17	No. 24	No. 29	No. 32	No. 37	No. 43	No. 46	No. 50
Clearing size	Letter B	No. 3	$\frac{3}{16}$ in.	No. 19	No. 27	No. 30	No. 33	No. 39	No. 43

Wood Screws

Size No.	00	0	1	2	3	4	5	6	7	8
Clearing size	No. 52	No. 51	No. 50	No. 44	No. 40	$\frac{7}{64}$ in.	$\frac{1}{8}$ in.	$\frac{9}{64}$ in.	$\frac{5}{32}$ in.	$\frac{11}{64}$ in.

WEIGHTS OF VARIOUS SUBSTANCES

(Lb. per Cubic Foot)

Liquids

Acid, nitric (91 per cent.)	94
Acid, sulphuric (87 per cent.)	112
Alcohol	49
Benzine	46
Gasoline	42
Mercury	849
Oils	58
Paraffin	56
Petrol	55
,, refined	50
Water, fresh	62
,, salt	64

Metals

Aluminium	165
Brass	520
Bronze	510
Copper	550
Gold	1205
Gun-metal	540
Iron, cast	450
,, wrought	480
Lead	710
Nickel	530
Platinum	1342
Silver	655
Steel	490
Tin	460
White-metal	460
Zinc	440

Soils

Chalk	170
Clay	135
Earth, loose	75
Gravel	110
Mud, dry	100
,, wet	120
Sand, dry, loose	100
,, wet	130
Shale	160

Stones, Masonry

Brick, pressed	150
,, common	125
,, soft	100
Brickwork	112
Cement	90
Concrete	140
,, reinforced	150
,, coke breeze	90
Flint	160
Granite	170
Lime	60
,, mortar	105
Limestone, compressed	170
Limestone, granular	125
,, loose, broken	95
,, walls	165
Marble	170
Plaster of paris	140
Rubble masonry	140
Sand, dry, loose	100
Sandstone	150
,, masonry	140
Slate	175

Timber

Ash	40
Beech	46
Cedar	28
Cherry	36
Chestnut	40
Cork	16
Cypress	30
Ebony	73
Elm	42
,, Canadian	45
Greenheart	70
Hickory	50
Jarrah	57
Larch	38
Mahogany, Spanish	48
,, Honduras	43
Oak, English	59
,, American	59
Pine, white	27
,, yellow	33
,, red	34
,, pitch	45
Plane	35
Poplar	26
Spruce	30
Sycamore	40
Teak	50
Walnut	41

Miscellaneous

Anthracite, broken, loose	54
Asbestos	187
Asphalt	88
Coal, bituminous	85
,, broken, loose	50
Coke	45
,, loose	30
Flour	40
Glass, window	160
,, flint	190
Grain, wheat	48
,, barley	39
,, oats	32
Hay and straw, in bales	20
Ice	59
Salt	45
Sulphur	125
White lead	197

Most die-sinking to-day is done on a die-sinking machine. The Keller machine is a powerful milling machine, operated by a simple electrical control. By means of this control the shape of a master is reproduced automatically by the machine. The job may be either profiling in two dimensions or the reproduction of reliefs in three dimensions. In each case a tracer passes over the master form and the cutter duplicates its path precisely. The cutting is controlled electrically to maximum cutter capacity regardless of the shape being duplicated.

The master forms used can be very simple. Light metal templates are sufficient for the heaviest profiling jobs. Solid masters may be wood or cement, or they may be finished tools which must be duplicated. Worn or broken dies can be used as masters and replaced directly with great economy.

Range of Work.—The machine is designed for the automatic production of blanking, trimming, or piercing dies and punches, extrusion dies, forging, stamping and diecasting dies, moulds for plastic materials, cams, templates, gauges, jigs, and metal patterns. It is ideally suited to the actual production of irregular-shaped pieces in experimental lots or short runs. With the precision locating attachment it becomes an excellent machine for producing accurate jigs and fixtures, as well as all types of work in which accurate relations must be maintained between bored holes, finished surfaces, slots, or milled impressions.

The accuracy of work produced on this machine is such that frequently very little or no hand finishing is needed. In other cases this machine requires much less time to bring a job to the final finishing stage than it would take for roughing alone on a hand-operated machine. Frequently several operations may be performed on the same machine with one set-up. For example, a die impression can be cut and holes bored or plugs set accurately in relation to that impression. A forging die cavity may be cut with the die mounted on the fixture, and then the edger can be cut automatically simply by laying the die on its back.

Work need not be repetitive for the electrically controlled Keller to save time and money. Masters are simply and cheaply made or readily available. Even if the full cost of a master is added to the cutting time on the machine, the result is often a substantial total saving.

Savings, not only in machine time but in hand-finishing time, help make the Keller machine a paying investment. With a Keller you can save money on two or more jobs simultaneously—the job on the machine and the job on the bench.

The Keller machine is not limited by the shape of the tool to be made, no matter how complex it is. Complicated dies can be produced as economically as ordinary ones, and frequently with even greater savings. This means that product design can be freed to a large extent from the limitations ordinarily set by die costs.

Broken or worn-out dies can be replaced rapidly and with little cost, thus reducing delays in production.

With a reduction in the cost of dies there is no tendency to continue using them beyond their economic life. The use of tools in first-class condition improves uniformity and eliminates delays in manufacturing and assembly.

The machine opens up new avenues for profit. Improved design increases product saleability. Tools rapidly produced allow the manufacturer to keep pace with a changing market, and the ability to supply accurate tools when needed gives the Keller-equipped contract shop an excellent competitive advantage.

Furthermore, the Keller machine concentrates the application of human skill where it belongs—in tool design and final finishing. The mechanical skill is a quality built into the machine. This quality is the toolroom's best fortification against the possibility of a growing scarcity of skilled tool-makers.

The Keller-equipped shop possesses the fundamentals of an extremely flexible organisation. It may expand its production readily during peak times without the slightest sacrifice in quality by operating the Keller machine to its fullest capacity. During slow times it can readily contract without destroying the organisation.

Finally, with the Keller machine the tool-room can be placed on the same basis as a production department. Tools will be produced exactly as planned. Costs

can be fixed and production schedules maintained with certainty. The machine has put the same degree of science into tool production that long since has been recognised in manufacturing departments.

Operating Principles.—The feature of the machine upon which depends its remarkable ability to follow practically any shape or contour is the automatic tracer control of the movements of the cutter. This control is so sensitive that the shape produced by the cutter is a faithful reproduction of the model.

The tracer is mounted on a bracket above the cutter, and the distance between the two is adjusted properly for the job to be done. From then on the tracer and cutter move in unison. The tracer follows the shape of the master form and the cutter duplicates that shape in the work. This is done by a very light tracer contact and electric control, so that reproduction is very accurate.

Operation of Profile Tracer.—There are two major types of operation under tracer control. The first of these makes use of a profile tracer which controls and guides only the vertical and horizontal movements of the machine, the cutter having been set to a given depth before the operation is started. Ordinarily, a thin metal template is used as the master in this type of operation. It can be either male or female.

The tracer point is in continuous contact with this master as it passes around it, guiding the path of the cutter to reproduce accurately its shape in the work-piece. The back of this tracer carries four contact points, corresponding to the up, down, right, and left directions. A very slight pressure of the tracer point against the master is sufficient to break one of these contacts and to make another. This changes the direction of travel by energising or de-energising the various magnetic clutches which drive all the movements of the machine. Consequently, the reproduction is very accurate, and there is never any danger of breaking through the outline of the master. This tracer is so sensitive that a movement of less than 0·001 in. on its point as it bears against the master will vary the direction of travel. Furthermore, this sensitivity is independent of the size of the cutter, of the depth of cut, or the hardness of the material. The cutter will be as accurately located for a heavy roughing cut in difficult material as for the lightest finishing cut.

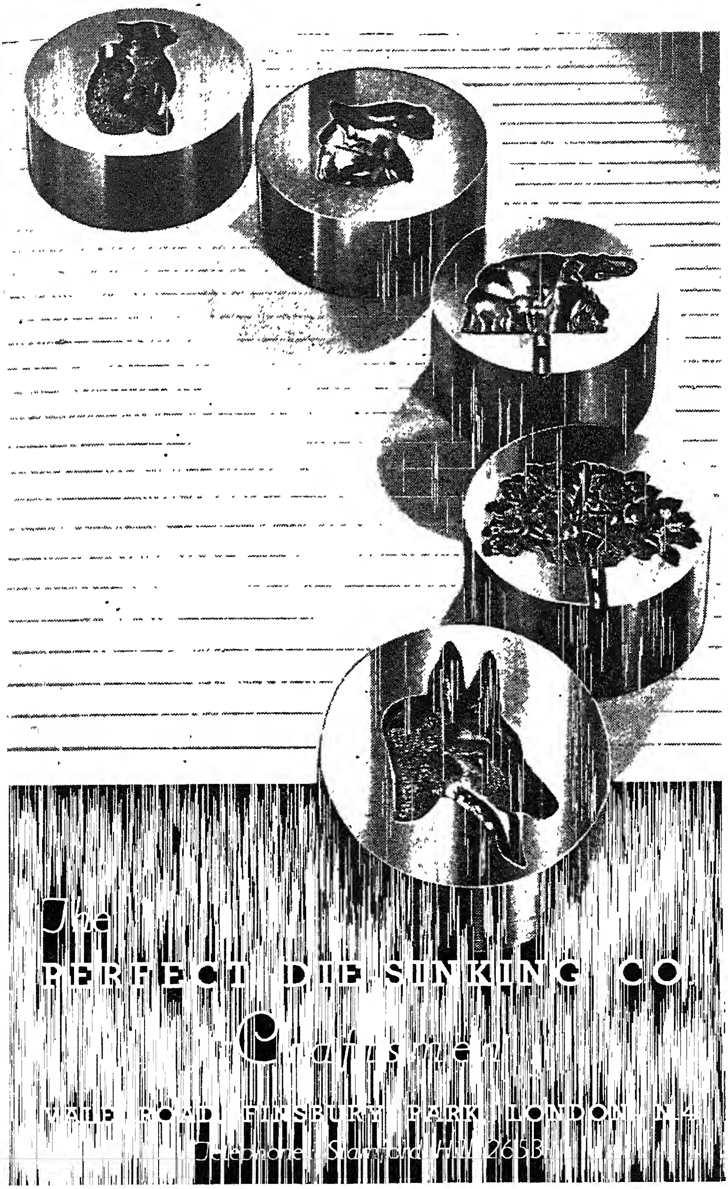
During the profiling cut the operator is required only to guide the tracer point toward the master and to determine the general direction in which it will follow the outline. He does this by means of a rotatable ring at the back end of the tracer. By means of light spring pressure, this establishes the general bias of the machine travel within each 90 degrees of the outline of the master. No great skill on the part of the operator is required.

The profiling operation is employed in the production of blanking dies and punches, trimming dies and edgers for forging dies, piercing and extrusion dies, cams, templates, and gauges.

Operation of the Automatic Tracer.—The second type of tracer control is used for three-dimensional work, either relief or impression. Once the machine is set it is fully automatic, requiring no guidance by the operator as in the case of profiling work. The automatic tracer is used instead of a profile tracer.

The controls of the Keller machine are set to cause the tracer to cover the entire surface of the master in a series of parallel strokes, either up and down or right and left. The lengths of these strokes are determined at the operator's option by adjustable table reversing dogs maintaining uniform length of stroke, traverse reversing dog operation at the surface outline of the cavity, or by hand, using a reversing switch. At the end of each stroke an automatic feed takes place before the next stroke begins. The amount of feed at the end of each stroke also may be determined in advance by a feed mechanism.

The third dimension is controlled by the automatic tracer. When its point is not in contact with the model, the machine is caused to travel in. From the moment contact is established, varying degrees of pressure on the tracer point (created by the contours of the model over which it passes) cause the machine to travel in and out accordingly. The automatic tracer responds to either axial or side pressure, and by means of interlocking relays it eliminates the horizontal or vertical motion while travelling either in or out. Consequently, it faithfully reproduces the complete form of the model, no matter how steep the sides of its cavities or elevations may be. This operation is employed for forging, moulding, diecasting, and forming dies.


The
PERFECT DIE SINKING CO.
Craftsmen
MALE ROAD FINSBURY PARK LONDON N.4
Telephone: Stamford Hill 2653

Combination Tracer.—A combination tracer also can be provided. This combines, with certain limitations, the functions of the automatic tracer and the profile tracer. It resembles the profile tracer in controlling the horizontal and vertical movements as the result of side pressure. Like the automatic tracer, it responds to axial pressure in controlling the in-and-out movement of the machine. It is limited to work having a cross section with rises and falls of not over 45 degrees. Its use is confined to the production of outlines running to varying depths rather than outlines that have a constant depth, such as would be produced by the profile tracer alone. A typical application would be machining the bead on a punch for an automobile side panel.

The profiling operation generally employs thin sheet-metal templates as masters. These templates may be filed easily from light stock. When a punch and die which must match perfectly are to be cut, the die template may be cast in type metal from the punch template, using a flask specially provided for that purpose.

The automatic tracer is operated from a solid master. This may be made of steel (perhaps a used or damaged die) or of an easily workable material, such as lead, cement, wood, bakelite, or any one of a number of artificial stones or pattern materials now on the market.

Two-tracer Attachment.—Certain forms can be cut by the use of a two-tracer attachment, which makes unnecessary the use of a solid model. With this device the profile and automatic tracers are used at the same time, the profile tracer following an outline template, while the automatic tracer follows a cross-section template. Forms in which the cross sections do not vary continuously can be produced in this way, usually employing one outline template and a series of cross-section templates representing the various cross sections of the form. These templates are the reverse of the series of checking templates that would ordinarily be used in producing a die of this type. Facilities are provided for interchangeably clamping them on the machine successively as the cut proceeds from one cross section to the next.

The Keller machine is equipped with hand wheels by which all movements may be accomplished and observed to 0·001 in. on dials mounted on the lead screws. In addition, all movements of the machine may be operated electrically by switches on the control cabinet. These two methods are used in setting up a job or in plain milling or boring. As an operator grows more familiar with the machine, he tends to use push-button control almost to the exclusion of manipulation by hand wheels.

At the end of each lead screw is a gearbox containing a pair of magnetic clutches driven by an individual adjustable-speed motor. The various rates of travel thus are adjustable independently through rheostat controls to the motor and by means of change gears. An especially designed step-by-step feed is actuated at the end of each stroke to feed the machine a predetermined distance.

The spindle is driven through vee belts from a motor mounted on the base of the machine. The cutter drive runs on ball and roller bearings throughout.

The slow-speed spindle has a No. 12 B. & S. taper and runs in bronze bearings. The high-speed spindle has a No. 9 B. & S. taper and runs on adjustable roller bearings.

To protect the cutter while running at maximum capacity there is an adjustable automatic feed control, the dial of which projects from the top of the control cabinet. This device automatically interrupts the feed when the power consumed by the cutter reaches a predetermined maximum. Thus the cutter is allowed to take power up to but not beyond the greatest load it can handle efficiently.

The adjustable intermittent feed, regulated by a knob on the control box, slows down the normal speed of travel by automatically interrupting it through a commutator. It permits operating the machine below the lowest-geared rate of travel. Very small end mills for jobs with delicate detail and narrow slots can be used at maximum cutting efficiency.

Because of its rigid construction, wide range of feeds and speeds, automatic feed control and adjustable intermittent feed, the Keller machine provides a unique combination of sensitiveness and ruggedness. It can use efficiently cutters ranging from face mills 4 in. in diameter to cutters $\frac{1}{8}$ in. or even smaller.

Precision Locating Attachment.—The positive electrical control of the Keller machine permits of a method whereby the spindle may be located anywhere in its full vertical or horizontal range within very close limits. This

feature is extremely valuable, and may be used either in conjunction with tracer control or independently of it.

In the production of progressive dies the impression can be reproduced from a template under tracer control, and correctly spaced in relation to other impressions, holes, and plugs by means of the precision locating attachment. Without change of set-ups, holes may be located and bored. The various impressions of multiple-impression dies can be reproduced from a simple unit master, with spacing accurately controlled by this attachment.

A variety of work may be done by the use of the attachment without relationship to tracer control. In general jig and fixture work the locating of holes, bosses, slots, and various milled surfaces is accomplished rapidly and accurately, and the necessary drilling, boring, and milling operations may be performed on the machine without change of set-up after each location is obtained.

The attachment consists of a specially graduated precision vernier scale carried by the horizontal table and another carried by the vertical slide. A vernier is mounted to slide easily along each scale and may be read to 0·001 in. Setting is made by lining up sharply drawn graduations on the scale and vernier with the aid of a fine-pitch screw. It is greatly facilitated by a ten-power flat-field magnifying glass and a built-in reading light. Another delicate screw adjustment for moving the scale relative to the vernier enables the operator to place his initial set at an even inch, and thereafter read his decimal direct from the print and set the vernier accordingly without the addition or subtraction of decimals in determining successive locations. The operation of setting the vernier does not entail any movement of the machine or work, but simply the movement of an easily adjustable instrument. Therefore it may be accomplished to a high degree of precision.

After the correct setting of the vernier has been made, the machine is moved toward location by merely snapping a switch. When the vernier slider touches a contractor held in a fixed position on the machine, the movement automatically stops. The spindle is then in location.

The precision of this device is independent of the condition of the lead screw, nut, or other moving parts, and its over-all accuracy is within the limits necessary for a wide range of precision boring and milling operations.

Occasionally it is necessary to produce two pieces which are identical except that one is a right and the other a left. Where an off shape is involved it is extremely difficult to obtain perfect symmetry by ordinary hand methods, either in the dies themselves or in the master to be used on a Keller machine. A right and left fixture is available for use with the Keller machine, by which both dies can be cut from a single master. In the process of cutting a left from a right, the master is mounted on a slide which moves synchronously with the horizontal travel of the machine, but in the opposite direction, resulting in mechanical accuracy of reproduction.

The Keller machine is frequently used for taking heavy preliminary cuts, and the furrows thus caused are machined out on the planer, shaper, or miller. Both layout work and fitting may be almost eliminated by using the Keller machine for finishing purposes, when blanking or raising tools having known formulæ are to be made. In the case, for example, of a blanking tool, a template of thin steel should be made to component size for the die opening, the size of the sheet being the same size as the die required. Centre lines at 90-degree axis should be marked on. The punch template, also with the centre lines marked on, should be made a perfect fit into the die template, tested over a light-box, with the centre lines coinciding. The die steel, ground on both faces, with both centre lines marked on, is secured on the Keller platen mounted on packing blocks. The die template is secured above it. It is also mounted on packing blocks, with the centre lines on the die steel and template in alignment. The die may then be machined in one cut, and on removal from the machine may be finished on a filing machine with the table tilted 1 degree to give a cutting edge. The punch steel is then secured on the Keller platen with the punch template above it, and with the centre lines in alignment. The punch may now be machined in two or more cuts, the cutting clearance between the punch and die being catered for by a variation of the diameters of the contouring pilot and the cutter. The amount of clearance should be equal to 5 per cent. of the metal thickness for soft brass, and 6 per cent. for hard brass and mild steel.

COUPLINGS

The term "coupling" is applied to a member which transmits torque (or turning effort) between two shafts which are intended to be in the same straight line. A coupling is used in cases where it would be inconvenient or impracticable to make the whole rotating mass as a single member. The coupling may be of a rigid nature, so that the shafts which it unites rotate as one; it may be designed in such a way as to transmit torque but not endwise or sideways thrust, or it

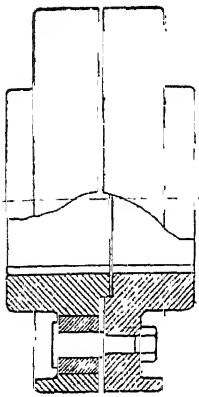


Fig. 1.—A rigid coupling.

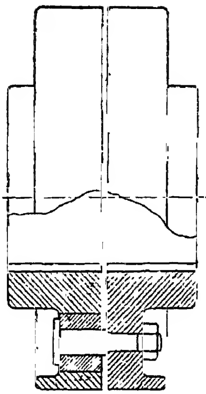


Fig. 2.—A pin-type flexible coupling.

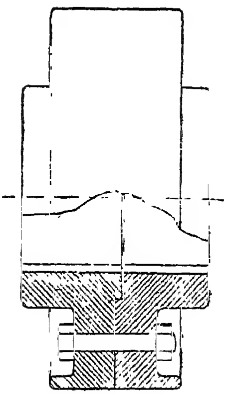


Fig. 3.—A pin-type flexible coupling (spigoted).

may be made so as to permit rapid connection or disconnection of the shafts either at will or automatically.

Couplings may be classified as follows:

(1) *Rigid:* Giving solid connection.

(2) *Flexible:* Transmitting torque but exerting little or no endwise or sideways control, and therefore preventing the transmission of any great amount of end thrust or side thrust from one shaft to the other.

(3) *Permitting Misalignment of Connected Shafts:* Transmitting torque between shafts which are not exactly in the same straight line. A coupling of this type may, or may not, transmit uniform angular velocity.

(4) *Permitting Angularity of Connected Shafts.*

(5) *Disengaging Couplings:* Permitting the connection to be made or broken by the movement of a lever or by mechanism controlled by the angular velocity of the shafts or by the torque transmitted.

Rigid Couplings.—In its simplest form (Fig. 1), the rigid coupling consists of a pair of discs each having a boss bored to fit on to the shaft. It is usual to provide one half with a spigot concentric with the bore, and fitting accurately into a corresponding recess in the other half. This makes sure that any lateral load exerted by one shaft on the other is taken by the spigot and not by the bolts which connect the two halves of the coupling.

It is highly desirable to arrange each half of the coupling with a circular flange which shrouds the bolt heads and the nuts. The coupling then presents a smooth outer surface, minimising danger from accidental contact with it when in motion.

In some circumstances it may be convenient to use one half of the coupling as a brake drum; this merely requires the section of the flange to be suitably shaped, possibly in conjunction with an increase of diameter.

When a rigid coupling is to be used, the shafts must first be lined up with extreme accuracy. If this is not done, the operation of fitting the coupling and tightening up the bolts is likely to produce excessive stresses in bolts and shafts and (what will quickly lead to trouble) excessive loading on the bearings.

In view of the danger thus arising out of misalignment, it is in general preferable to avoid the use of rigid couplings, although this recommendation may be relaxed where the distance between adjacent bearings is large compared with the diameters of the shafts. In such cases, the flexibility of the shafts tends to reduce the stresses arising out of misalignment.

The reader is referred to the section on ball and roller bearings for details of methods of mounting shafts and of self-aligning bearings and types. Bearing manufacturers, it is recommended, should be consulted in all cases where couplings are subjected to heavy loads. They will advise as to the type of bearing and methods of mounting.

Applications.—Rigid couplings may be used to permit reduction of a long drive (e.g. a marine propeller shaft) to more convenient lengths of shaft. Another application is in cases where it is desired to take part of the weight of the rotating members of one machine on the bearings of an adjacent machine. For instance, the rotor of a "single-bearing" electric generator is supported partly by the bearings of the driving unit, which may, for example, be an engine. The rigid coupling used in such circumstances has to transmit shear force and bending mo-

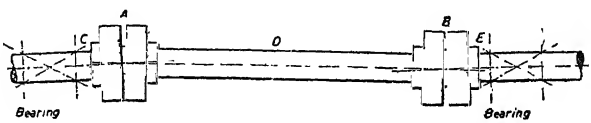


Fig. 4.—Misalignment permitted by two spigoted flexible couplings.

ment, in addition to the twisting moment, corresponding to the transmitted power. In theory it is possible to design the shaft and coupling layout so that the coupling is at a "point of contraflexure" where there is no bending moment, but it is hard to ensure in practice that this is actually the case.

It is sometimes possible to forge the flange of a rigid coupling in one piece with the shaft, and this has the advantage of eliminating the key which is otherwise necessary, and of avoiding the accurate machining involved in fitting the separate half-coupling. On the other hand, the cost of the shaft forging is higher per unit of weight than it would be for a parallel shaft of similar steel.

Flexible Couplings.—A flexible coupling may take one of a number of forms, and there are on the market several proprietary designs which give "flexibility" in greater or less degree. There is a tendency to assume that a flexible coupling allows for errors in lining up the shafts, and whilst this is true in a limited sense it should be understood that misalignment will lead to eventual failure even of a flexible coupling, either by wear of sliding elements or by breakage resulting from fluctuating stresses in flexible elements.

The use of a flexible coupling generally requires that the two shafts which it connects shall be completely supported by their own bearings. In special circumstances, however, this restriction does not apply.

It should always be remembered that a flexible coupling cannot entirely prevent transmission of end thrust or side thrust. All it usually does is to reduce such thrusts to much smaller amounts than in the case of a rigid coupling.

Brief descriptions of the commoner types of flexible couplings are given below.

Pin-type Flexible Couplings.—In general construction the pin-type flexible coupling (Fig. 2) is similar to the rigid coupling, except that the bolts are replaced by pins held rigidly in one half of the coupling and each carrying a bush of soft material fitting into a hole in the other half. The opposing faces of the two halves of the coupling are initially separated by an amount which is large enough to prevent contact in spite of end float or relative expansion of the shafts. A

central spigot and register are sometimes provided, the idea being to provide for sideways location where one of the shafts needs support from the other. (See Fig. 3.)

The bushes are usually of rubber, preferably treated in such a way as to minimise the effects of "ageing" or of contact with oil. The common practice is to make the bushes of plain cylindrical form, fitting fairly tightly on the pins but having a small clearance in the corresponding bore in the coupling flange.

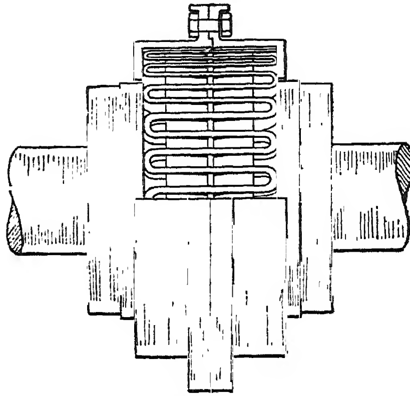


Fig. 5.—A Wellman Bibby coupling.

The bushes are sometimes made of other materials such as leather or raw hide, but rubber of a suitable grade is probably the best for the purpose. It has exceptional "resilience" or ability for storing energy, and it is not harmed even by severe distortion, so that it can stand a considerable amount of punishment whilst providing useful flexibility.

Bearing Loads.—In the case of a long shaft supported by a number of bearings, pin-type couplings may be used to prevent the production of excessive bearing loads by slight misalignment. (As already mentioned, the couplings must not be expected to compensate for any considerable errors in erection.) For example, the couplings A and B in Fig. 4 may be of the pin type, provided with spigots to take the weight of the shaft D, and by permitting slight angularity between shafts C and D and between shafts D and E they allow for a type of alignment error shown, in a greatly exaggerated degree, in the diagram.

Wellman Bibby Flexible Coupling.—The Wellman Bibby flexible coupling (Fig. 5), which is known in America as the "Falk" coupling, is made entirely of metal and is widely used in very heavy service. It consists essentially of

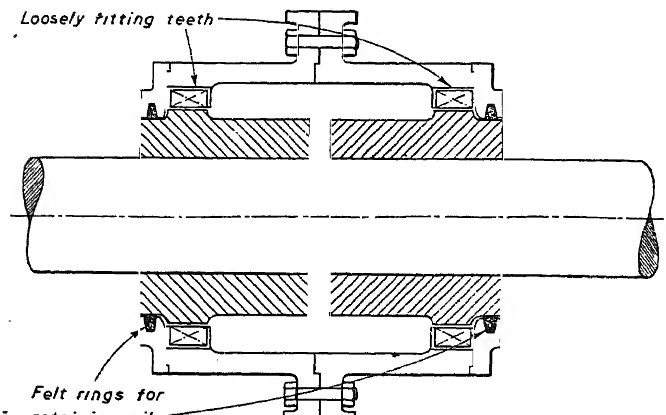


Fig. 6.—A claw-type coupling.

two flanged members having slots running parallel to the shaft and containing zigzag springs of rectangular section forming the elastic connection between the two halves of the coupling. A thin steel cover of cylindrical form is bolted to one half of the coupling and extends over the other half, enclosing the springs and retaining the grease with which they are lubricated.

The slots are "flared" in such a way that, as the torque on the coupling increases, the relative angular deflection between the two halves causes the free length of each limb of the spring to be shortened. In this way the maximum stress in the spring is not appreciably increased even under heavy overloads.

Claw-type Flexible Coupling.—Used principally in cases where prevention of transmission of end thrust is important, the claw-type coupling (Fig. 6) does not contain any elastic element. The driving and driven parts are each in the form of a hub with outwardly projecting teeth. The connecting member is a sleeve having two sets of inwardly projecting teeth which fit, not too closely, between the teeth of the driving and driven members. The teeth must be lubricated, and this may be done by packing the sleeve with grease, which is prevented from leaking away by special retaining plates at the ends of the sleeve. The

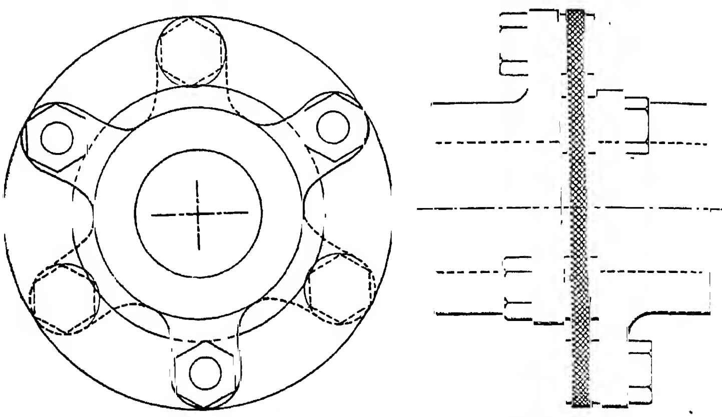


Fig. 7.—Hardy disc coupling.

claw-type coupling permits very small errors in the alignment of the shafts, at the expense of a tendency to wear of the teeth.

The claw-type coupling is often used to transmit the output of steam turbines, and in such cases it is usually enclosed in a stationary oil-tight casing and is provided with a positive oil feed.

A modification of the claw-type coupling is used in the "central" drive for tube mills. In effect the sleeve is extended to form a "torsion shaft" connecting the low-speed shaft of the driving unit to the trunnion of the mill. Owing to the length of this shaft, a comparatively large error in alignment causes only a small error of angularity between the torsion shaft and the shafts to which it is connected.

The Hardy Disc.—A flexible coupling which enjoys a wide vogue in automobile practice is the Hardy disc type (Fig. 7). To each shaft is keyed a spider with three arms, each of which carries a pin. The six pins pass through a fabric disc at equidistant concentric points, and the flexibility of the disc permits angularity between the shafts.

The cardan shaft is provided with a Hardy disc coupling at each end and, by changing its angular position, permits the relative vertical movement of the gearbox and rear axle.

It is usual to locate the end of the cardan shaft in relation to that of the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adjacent shaft by a ball-and-socket joint or its equivalent. This relieves the fabric disc of loads which would otherwise be applied to it by centrifugal force if the cardan shaft were out of balance.

Simms-Jurid Coupling.—The Simms-Jurid coupling (Fig. 8) is similar

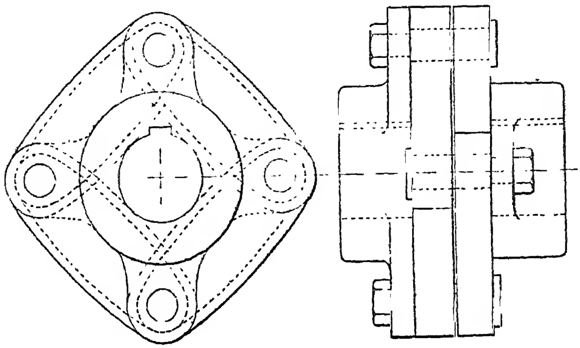


Fig. 8.—Simms-Jurid coupling.

to the Hardy disc coupling, inasmuch as each half is in the form of a spider, but the fabric disc is replaced by a number of steel cable links embedded in rubber. Each link is in the form of an elliptical loop of cable, the driving effort being a tension along the major axis. Application of load to the coupling tends to make each cable link into a flatter ellipse. This effect is resisted by the rubber, which thus gives the coupling flexibility in the torsional sense as well as permitting slight errors of alignment or angularity without giving rise to excessive shaft loading.

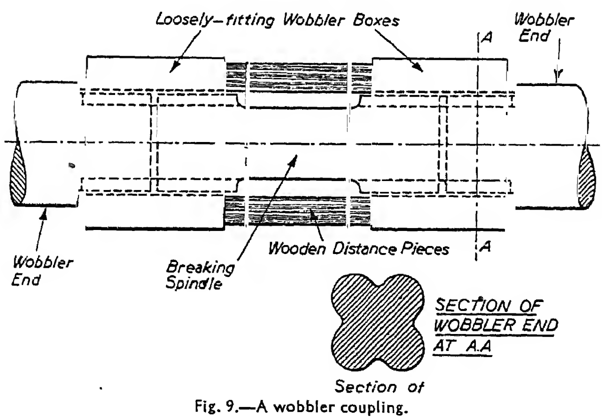


Fig. 9.—A wobbler coupling.

Wobbler Coupling.—Although of relatively crude design and construction, the wobbler coupling has qualities which cause it to be unrivalled in rolling-mill work. The connection between each mill pinion and the corresponding roll is through a " breaking spindle " (designed to avoid other more serious damage by fracturing under severe overload) and two wobbler couplings.

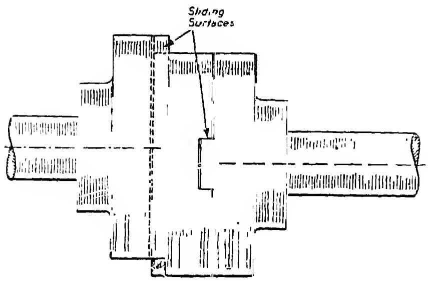


Fig. 10.—The Oldham coupling.

The ends of the roll-necks and the pinion necks are of special section (Fig. 9), something like the shape of a four-leafed clover, and the breaking spindle is provided with a corresponding loosely fitting sleeve at each end. By sliding one of the sleeves towards the other, the overall length of the spindle may be reduced sufficiently to permit its removal, thus severing the connection between pinion and roll. In operation, the hollow elements are held apart by pieces of wood lying in the grooves in the spindle and bound in position by coils of wire. The great advantage of this primitive form of locking device is that it can be replaced at negligible cost should it be destroyed by breakage of the spindle. Furthermore, it tends to prevent broken pieces of the spindle from being flung about by the shock of sudden fracture.

Oldham Coupling.—The Oldham coupling (Fig. 10) is designed to connect shafts whose centre lines are parallel but not in the same straight line. The distance between the centre lines of the shafts does not usually exceed the radius of the smaller shaft.

The driving and driven parts of the coupling are similar to those of a rigid coupling, but in the face of each flange is a radial groove extending across the full diameter of the flange, and therefore having open ends.

The third member is a circular plate of about the same diameter as the flanges. Each face is provided with a tenon, which slides in the slot in the coupling flange. The two tenons are at right angles to each other.

Any sideways movement of one shaft relatively to the other amounts to the same thing on two separate movements, one parallel to each tenon, whatever the angular positions of the tenons may be. As each tenon can slide in its slot, movement in each of the necessary two directions can take place and the presence of the coupling does not interfere with sideways relative movements of the shafts.

The amount of permissible misalignment is limited only by the diameters of the flanges and of the central plate and by the allowable rubbing speed between tenon and slot.

In another form of the Oldham coupling the central member is connected to the other parts by links which (for small errors in alignment) allow the same sorts of movement as do the tenons and slots. This rather more expensive construction has the advantage of giving lower rubbing speeds than would occur in the ordinary type of Oldham coupling.

Hooke's Joint.—The Hooke coupling (Fig. 11) consists of a star-piece having four equidistant arms, the pairs of which are pin-jointed into forks carried by the driving and driven shafts. The connection thus permits relative angular displacement of the shafts about two perpendicular centre lines (the centre lines of the two pairs of pins) and therefore any relative angularity can be accommodated.

The relative angular velocity of shafts connected by a Hooke's joint changes twice in each revolution

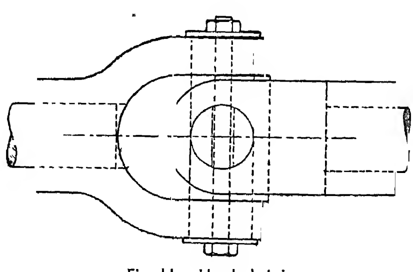


Fig. 11.—Hooke's joint.

according to the angular position of the star-piece) between cos A and sec A, where A is the angle between the shaft centre lines. This form of coupling is suitable only for comparatively low speeds. If the speed is high or the angularity severe, the changes in speed set up heavy loads in the shafts, especially if there is "flywheel effect" in the machinery concerned.

Double Universal Coupling.—Two parallel shafts which are not in the same line may be connected by a cardan shaft provided with a Hooke's joint at each end. Provided that the forks of the joints are correctly set in relation to each other, the variation in angular velocity produced by one joint cancels that produced by the other joint and the two parallel shafts rotate in unison with each other.

This arrangement constitutes a "double universal coupling" which permits the connected shafts to have considerable misalignment provided that they remain parallel.

It is not necessary to use a long cardan shaft, and, in fact, there need not be one at all, in which case the central member of the coupling is just a boss with a fork at each end. However, a cardan shaft of reasonable length gives the advantage of small angularity for any particular amount of misalignment, and the amount of rubbing on the pins is therefore small.

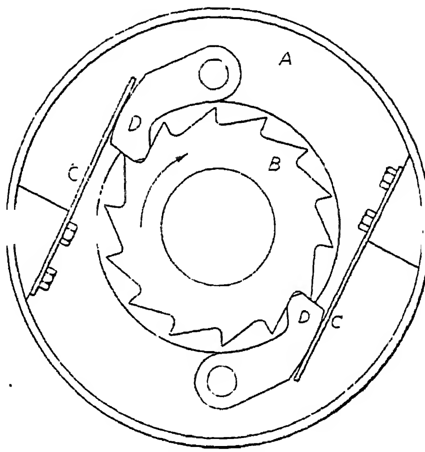


Fig. 12.—A ratchet coupling.

The commonest type of disengaging coupling is that which consists of two sleeves each having projecting "dogs," "jaws," or "claws." One sleeve is rigidly fitted to its shaft, whilst the other is fitted to the other shaft in such a way that it can slide along the shaft under the control of an operating lever. The shafts are arranged on the same centre line with their ends almost touching, and each can drive the other when the two sets of coupling jaws are in engagement. By sliding the movable sleeve along its shaft so that the jaws are separated, the drive can be quickly disconnected.

This type of disengaging coupling is sometimes provided with jaws having sloping "back faces." This makes engagement of the coupling easier but limits the transmitted torque to one direction, that is the one in which the forces between the halves of the coupling are exerted on the radial faces of the jaws. Any attempt to transmit torque in the opposite sense puts loads on the sloping faces of the jaws and tends to slide the movable sleeve out of engagement.

A device of a somewhat similar nature is the speed-controlled ratchet coupling (Fig. 12). This is employed in cases where a machine has occasionally to be driven by an auxiliary motor at a low speed and the main motor is required to pick up the load without stopping.

In Fig. 12 the outer member A is fixed to the driving shaft of the machine, and this is connected to the main motor at some other point. The ratchet disc B is driven at low speed through gearing by the auxiliary motor. Rotation is clockwise.

When the coupling is at rest the flat springs C hold the pawls D in engagement with the ratchet teeth, and when the auxiliary motor is started the drive is taken from B to A through the pawls. When the main motor is started, it drives A

at a higher speed than that produced by the auxiliary motor and so the pawls trail over the ratchet teeth.

Atlas Anti-friction Coupling.—The Atlas coupling makes use of the toggle principle in a friction-clutch coupling. In Fig. 13, case A is bolted to back plate B keyed to "live" shaft. Front plate E screws into case A, which contains two friction plates D, D with hardened steel discs let in, as shown. These friction plates are carried by hub C and drive it through two feathers C′, C′ let in and screwed to the hub, which itself is keyed to the "dead" shaft. Tightening toggle levers F, F have chilled slots, each containing three hardened steel rollers H, H, H, which work against the hardened steel discs of friction plates, D, D. Ends of tightening levers F, F are moved to and fro by studs riveted to shifting fingers K, which are let in and screwed to shifter G. G is actuated by shipping lever T forked at its upper end, the limbs of the fork being pivoted on either side of the loose ring R, carried in a groove on G. Ends of forked limbs are connected by links V to a similar loose ring P carried in a groove on E. Pins S, S, rigidly secured

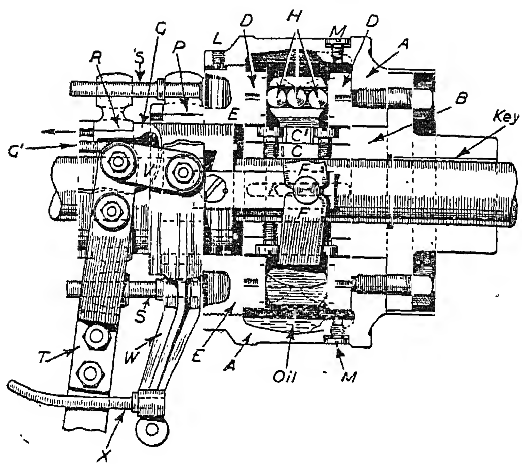


Fig. 13.—The Atlas anti-friction coupling.

to P, and passing through holes in R, prevent the rings from revolving independently of each other, while allowing R to move longitudinally independently of P. When lever T is moved the ends of forked limbs remain stationary, while pivots of the same, and consequently loose ring R and shifter G, slide longitudinally on the shaft. Ring P on the plate E carries an arm W, the end of which is an eye to which a stay rod should be attached. W also carries an iron loop X on which lever T works. When clutch is at work, lever T, hanging in a vertical position, does not tend to actuate clutch in any way. When P is pulled back to disengage position its weight tends to put the clutch in action again, but is prevented by a constriction near the end of the loop X.

Clutch is shown almost in gear. When shifter G is pressed home the rollers in contact with friction plates are carried slightly above and below the centre line, which prevents any tendency to involuntary disengagement. To disengage clutch, shifter G moves in direction of arrow, which tilts slot in levers F, F and removes roller pressure from friction plates. This toggle action, being dependent on roller friction only, exerts enormous power with a comparatively small expenditure of force.

ELECTRIC

Types of Motor.—Electric motors are used on portable tools of many types, such as drills, emery wheels, flexible shaft grinders, blowers, polishers, sanders, screwdrivers, pumps, conveyors, hammers, etc. The larger-powered tools of, say, 1 h.p. or over are often D.C. motors or 3-phase A.C. motors of the squirrel-cage type, the standard 3-phase supply being at 400 volts between each of the 3 phases, that is 230 volts between any one phase and earth, and at 50 cycles. Since a desirable feature of portable or transportable tools is light weight, such motors are generally high-speed machines running at a speed between about 3000 r.p.m. on no load to about 2850 r.p.m. on full load, such machines being smaller and lighter than slower-speed motors of the same horse-power. The maximum possible speed of a plain induction motor operating from a 50-cycle supply is 3000 r.p.m.; lower-speed motors operating from such a supply are designed for no-load speeds of 1500, 1000, 750, or 600 r.p.m.

Portable tools below 1 h.p. to ½ h.p. may be driven by D.C. motors or by single-phase A.C. motors. Single-phase A.C. motors may be induction motors of the split-phase, capacitor, or repulsion-starting type having no-load speeds similar to those of the 3-phase type. The characteristic of 3-phase and single-phase induction motors is similar to that of D.C. shunt motors, as indicated in Fig. 1. It will be seen that the fall of speed between no load and full load is only a few per cent. of the no-load speed. Other small motors operating from a single-phase A.C. supply may be repulsion motors or series (universal) motors, the latter type of motor being designed to work on either A.C. or D.C. The characteristic of repulsion motors and series motors is shown in Fig. 2, from which it is seen that they run at a low speed when heavily loaded, whilst the speed may rise to a very high value on light load.

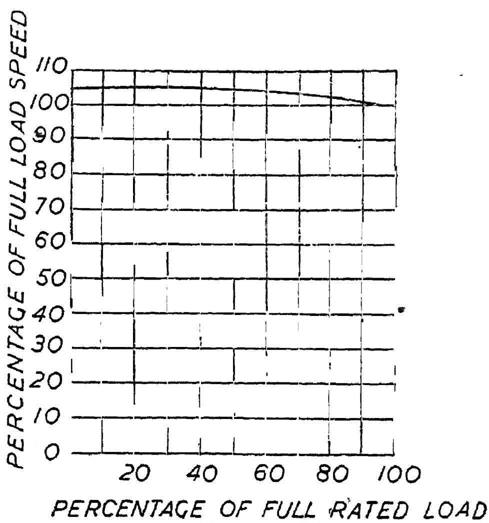


Fig. 1 —Typical characteristic curve for induction motors, repulsion-starting induction motors, and D.C. shunt motors.

A feature of the design of repulsion motors and series motors used on drives which may become unloaded is to ensure that the excessive speed in such circumstances does not cause very heavy mechanical stresses to be set up in the rotating parts. There will also be high stresses on driven plant such as emery wheels. The breakage or slipping off of a belt may be responsible for a motor failure of this description. In many cases, such as portable drills which drive through gearing, the friction of the gearing alone is sufficient to prevent a dangerous rise of speed on light load; but where plain repulsion motors or series motors are used on drives having little friction, such as emery wheels, the switch

should be mounted as near as possible to the cutting point and should be used to stop the motor when it has completed a cut.

Features of Design.—For most portable or transportable electric tools used in engineering workshops, a totally enclosed case capable of excluding dirt, grease, or metal dust is desirable for the motor, but such enclosure prevents ventilating air from passing over the motor windings and necessitates the fitting of a larger motor to provide adequate cooling. The use of enclosed motors is therefore generally restricted to transportable tools fitted with wheels. The majority of portable tools have a motor case which allows ventilating air to be drawn through, generally assisted by a fan inside the motor, the openings in the case being small enough to prevent the operator's fingers getting inside.

Connections.—The internal connections of the various types of motors used on portable and transportable tools are shown in Fig. 3; a common feature of such machines is a flexible cable which must be used to supply them. This cable should incorporate an earth wire by means of which the motor frame and switch case can be connected to metalwork making sound connection with earth, such as a mains cold-water pipe. This necessitates a 4-core flexible cable being used for a 3-phase motor and a 3-core cable for single-phase and D.C. motors. In the case of 3-phase motors, the connection between the flexible cable and the fixed wiring may be made by means of a 4-pin plug and socket, or ironclad socket and ironclad 3-pin plug, the earthing lead being connected to the fourth pin or the ironclad case of the plug. Single-phase and D.C. motors may be connected up with 3-pin plugs or 2-pin ironclad plugs with the third pin or plug case used for the earthing connection. It will be realised that the method often adopted, of connecting a portable electric tool through a lampholder and adaptor, provides no connection to earth, and in any case the contacts of lampholders are not designed to carry motor currents. Many accidents have occurred due to inadequate earthing of portable electric tools, and the earth wires must be properly connected and maintained to avoid risk of shock in the event of the insulation failing. Should a tool become "alive" the operator may be unable to relax his grip; this special risk in the case of portable motors has been recognised by the Factory Acts requirement that portable motors on A.C. supply, and on D.C. supply over 150 volts, shall be earthed, whilst fixed motors over 125 volts A.C. or 250 volts D.C. require earthing. An adequate number of sockets should, therefore, be fitted in places where the portable tools may be used. Flexible cables should be firmly secured at the plug and motor or switch by some method which does not allow strain to be placed on the copper conductors. The cables should be

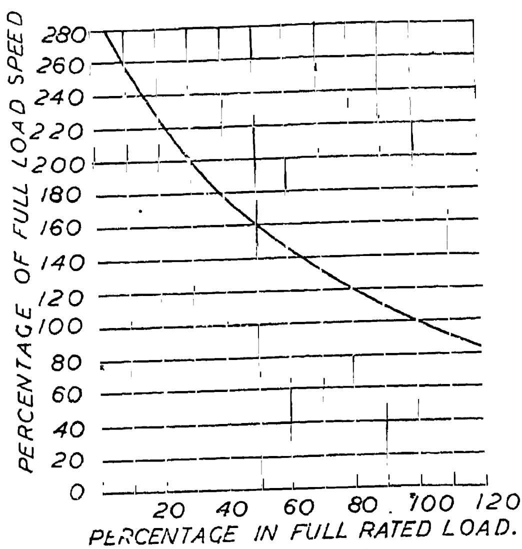
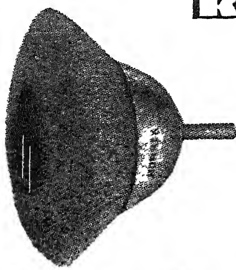
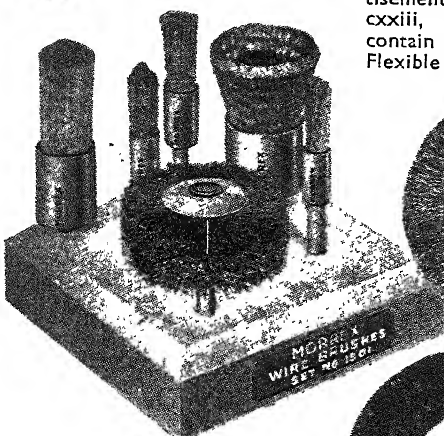
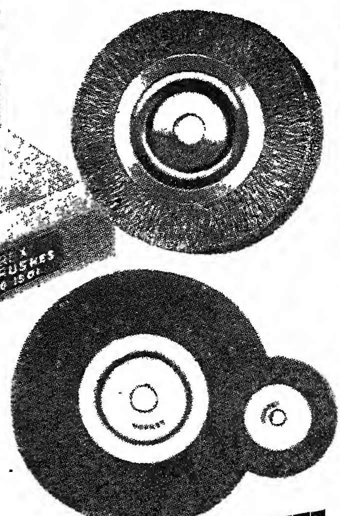


Fig. 2.—Typical characteristic curve for repulsion motors, universal motors, and series D.C. motors.







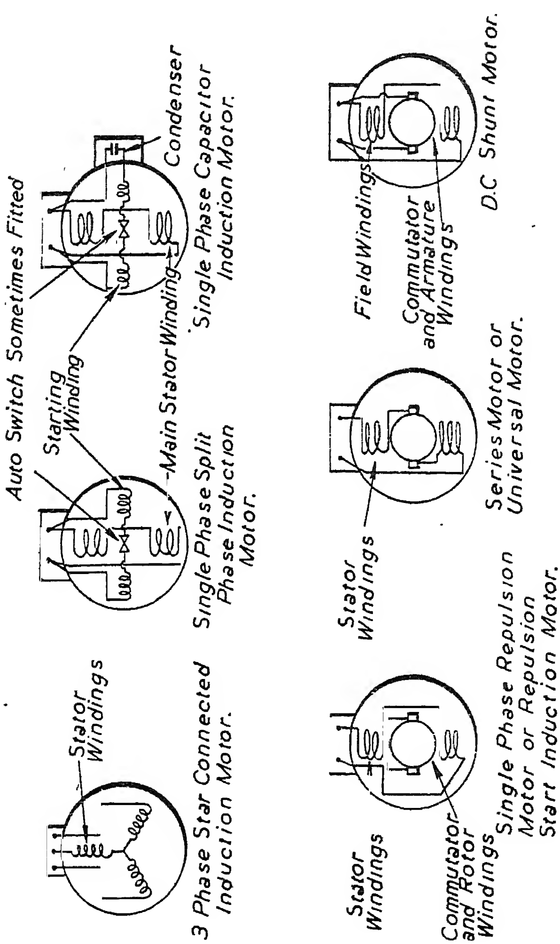


Fig. 3.—Internal connections of portable-tool motors.

long enough for the job, but not too long as they are liable to get tangled and may cause people to trip up. If necessary, an extension flexible cable can be made up with a 3- or 4-pin plug at one end and a socket at the other end.

Starting.—Most portable electric tools are started up by a switch which connects the motor directly to the mains. In these circumstances the motor may take a momentary current several times greater than the full-load working current. A point which does not always receive adequate consideration is that the switch should be designed so that the contacts can readily be examined from time to time, as the frequent operation of these switches may cause the contacts to become worn and burnt.

Overload.—Portable electric tools should be protected against overload and the effects of failure of the insulation, which might otherwise cause serious damage to the motor or electric shock to the operator, by the use of fuses or overload trips of the magnetic or thermal type. The fuse wire used should be just large enough to allow the motor to start up without melting of the fuses, pure tin wire being useful for small motors. For 3-phase motors it is particularly necessary that the fuse wire used is the same size in each pole, as non-observance of this rule has been the direct cause of many burnt-out motors. Should one fuse wire melt, the fuse wire in each of the three poles should be renewed. Correctly rated overload releases can be used to give better protection against overload than fuses, which cannot protect a fully loaded motor against less than about 100 per cent. overload. Most thermal overload releases have an inherent overload

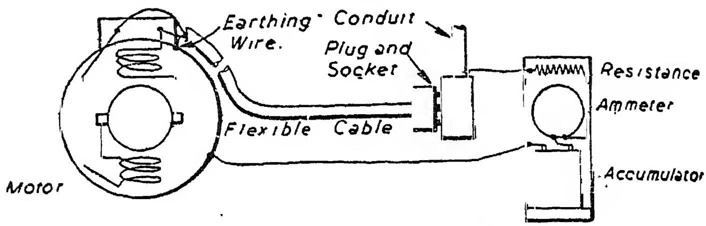


Fig. 4.—Simple testing set for flexible cables.

capacity somewhat similar to that of the motor, which requires that the release be set at the full-load current of the motor to provide proper protection. Should a smaller motor be plugged in without alteration of the fuses or overload setting, which is the usual procedure, the smaller motor will not have proper protection. This difficulty may be overcome in the case of transportable tools and the larger portable tools by fitting the fuses or overload protective device actually on the tool or motor. For the smaller portable tools a different type of plug, which can be plugged only into circuits protected for that particular size of machine, may be used.

Maintenance.—To prolong the life of portable electric tools the machines should be examined regularly, say every two or three months, the interior of the motor and the ventilating openings in the case being cleaned or blown out. If the motor is a D.C. machine, repulsion or repulsion-starting induction motor, the brushes which are fitted on these motors should be checked to ensure they are not worn out, that they are clean and free, and have adequate pressure on them. Any grease, dirt, carbon, or metal dust which may have accumulated in the motor should be carefully cleaned off, special care being devoted to the commutator and brushgear where the insulation is generally of small dimensions and may be bridged across with conducting matter. The commutator fitted on these machines should be cleaned out and, if necessary, smoothed up with carborundum cloth. In the case of repulsion-starting induction motors and many split-phase and capacitor motors, an automatic switch is fitted on the rotor which operates when the machine has speeded up at starting. This should operate with a decided click and without hesitation; otherwise it is advisable to dismantle the motor as far as may be necessary to clean and lubricatet he gear.

Earthing.—Maintenance of earthing is important: operators may be chary of using portable tools once one of them has had a shock. The best way of testing the earth wire of a flexible cable is to plug in with the motor switch off and pass a current of about 3 to 5 amps. between the motor case and the fixed earthing system such as the conduit, making sure the earthing lead is not short-circuited by the tool resting on metalwork which may be in contact with earth. The test set may consist of a 2-volt accumulator in series with a resistance unit of about 0·4 ohm and an ammeter which will read up to 5 or 6 amps., as indicated in Fig. 4. The earth lead can be considered correct if a reading of 3 to 5 amps. is obtained. This test method has the advantage of testing both the lead itself and the connections at the socket; also, if several strands of the earth wire have become broken by bending through constant use, the remaining strands will probably be fused by the test current.

Provided the motor is properly earthed, it should be impossible for the operator to receive a shock from the frame. Should, however, the earthing be inadequate, due to a broken earth wire, loose earth connection, fuse wire too large, overload setting too high or auto-switch mechanism too stiff, or main earth connection not being taken to a point making sound connection with earth, a shock may be received under certain conditions. If the main earth connections are not sound, a fault on one machine may cause the operators on several machines to receive a shock.

Lubrication.—The grease provided in ball-bearing motors will, in most cases, be serviceable for many months. Often it is necessary to open up the bearings for regreasing, and in such cases it is wise to take the opportunity of washing out the old grease with petrol or paraffin before repacking the bearings about three-quarters full of new grease. The state and quantity of oil in any gearing which may be fitted should also be checked periodically. Where motors are fitted with sleeve bearings, the oil is often absorbed in cotton packing in the housing. For such machines it is best to have a regular routine for oiling, so they are not neglected, adding a small quantity of oil to each bearing about the first of each month.

Many of the troubles experienced with electric tools are due to overload, and it is important that a machine large enough for the proposed duty is obtained. The correct type of grinding wheel, drill, or other cutting tool should be used for the work in hand, the tools should be kept sharp, and the operator should not exert undue pressure on the tool. Further causes of lack of power in portable electric tools are badly worn or sticking brushes, broken connection in armature winding, or stiff motor or gearing, possibly due to the machine not being properly assembled after overhaul.

Sparking.—Excessive sparking at motor brushes may be due to a broken connection in the armature (in which case one or two adjacent commutator segments will probably be burnt), commutator out of truth, worn or sticking brushes, brushes of the wrong grade or with incorrect pressure. A further cause of sparking with new brushes may be due to their not being properly bedded to the commutator. The brushes should be bedded by inserting a piece of carborundum cloth between brush and commutator, this being pulled round the commutator in the direction of rotation whilst applying pressure on the brush.

Overheating.—Overheating of a motor may be due to overload, stiff gearing, broken fan, restricted ventilation due to dirt or other foreign matter, short circuit in the motor, or, in the special case of 3-phase motors, may be due to a worn or burnt contact on the switch or plug, loose connection, broken wire in the flexible cable, or the melting of one fuse. With a loose connection, bad contact, or broken wire a 3-phase motor would probably not be self-starting, whilst one melted fuse will certainly prevent its restarting. In the case of certain split-phase and capacitor motors, overheating may be due to the sticking of a centrifugal switch in the motor, causing current to flow continuously through the starting windings. The cause of overheated motors should be investigated at once, as prolonged overheating is liable to cause the windings to burn out. Overheating of a switch is usually due to a faulty contact or loose connection, although it may also occur if the moving-iron cores of coils are not free to move right home.

The failure of a motor to start when switched on may be due to a melted fuse, broken or disconnected wire, sticking brush, seizure of motor or driven shaft,

sticking of automatic gear in repulsion motors and certain split-phase and capacitor motors, bad contact in switch, or sticking of the mechanism.

PNEUMATIC TOOLS

Pneumatic tools have no tendency to heat up in use; instead, there is a tendency towards automatic cooling because of the exhaust of air.

When comparatively few low-power tools are used the pneumatic variety generally show to advantage, due to the fact that they can be run from the air line which is, no doubt, already installed; a pressure of 80–100 lb. per sq. in. is desirable, but a lower pressure than this can be used. In other circumstances it is more difficult to make a choice between the two types, and the decision must be governed by the conditions applicable to each individual case.

Drills.—Pneumatic drills are produced in all capacities from ⅛ in. to 3 in. Additionally, these are available with different types of chuck, alternative push-button, trigger, or lever throttle control, straight or angle head, with or without offset handle.

There is a rotor with four bakelised fabric vanes, which are loosely fitted into slots. This fits inside a cylinder through which there is a line of inclined ports. Compressed air is directed through these ports on to a vane, and as a result the rotor is caused to turn on its bearings. When this happens the vanes are thrown outward by centrifugal force so that they form a seal within the cylinder. Continued air pressure keeps the rotor in motion.

The necessary speed is governed by the diameter of the drill to be used, and can be controlled during manufacture by varying the diameter of the ports. A drill with a capacity up to ⅛ in. has an approximate speed when running light of 4000 r.p.m., whereas a drill having a capacity of 3 in. has a speed of between 65 and 100 r.p.m.

Reversible Drive.—Drills have been taken as examples of portable pneumatic tools, but there are screwdrivers, nut runners, grinders, sanders, woodborers, circular saws, tappers, wrenches, and other tools operating on the same general principle. In the case of many of these the drive is reversible; this is arranged by providing two sets of inlet ports, pointing in opposite directions, and fitting a slotted sleeve round the cylinder which can be turned to either of two positions.

Riveting Hammers.—A different arrangement is used for riveting hammers, chipping and caulking hammers, scaling hammers, and corresponding tools. These have a reciprocating piston and a two-way valve. The piston in moving backwards and forwards strikes the end of, say, the rivet set. Riveting hammers can be obtained in either fast-hitting or slow-hitting, long-stroke types, the number of blows per minute varying from about 650 to 4500.

Yet another type of riveter is the compression riveter, which has been specially produced to meet the requirements of sheet-metal workers, especially those engaged in aircraft production. The tool is noiseless in operation and can, of course, be used when dealing with alloys subject to work-hardening if given repeated blows.

There is also a series of yoke riveters, these being so designed that they can be used on gaps of varying width. Additionally, the yokes are interchangeable, and there is an extensive variety of shapes and sizes.

Shearing Machines.—The portable shearing machines can shear metal sheet of between 18 and 12 S.W.G. The tools are convenient to hold, and it is possible to cut a straight or curved line through several feet of sheet metal. The head is shaped so that the operator can follow the line without difficulty, whilst the cutters are easily reground, adjusted, or replaced when the need arises.

Hydro-pneumatic Squeeze Riveters.—Squeeze riveters of the hydro-pneumatic type have been produced to accelerate the riveting of light structures, particularly of the aircraft type. A typical riveter of this type comprises an intensifier having a large air cylinder, with a small hydraulic cylinder mounted immediately above it in tandem. The total load of the air piston is concentrated on the small area of the hydraulic ram, the resultant fluid pressure being thirty-six times greater than the air pressure used. A flexible steel-armoured hose transmits this high pressure through an operating cylinder which is attached to the actual riveting yoke. With such a unit the operator is able to reach difficult working positions, and riveting pressures up to 15 tons can be applied without fatigue:

The extent to which a cutting tool is wearing can largely be ascertained from the tint, form, and dimensions of the chip. When steel is being turned, the chips thrown off will in the beginning be long, straight, and not very spiral in form. Their hue will be blue or purple when the cutting speed is correct. The colour shows the generation of too much heat at the cutting edge, even though the tool is freshly ground and has been in action for only a small portion of its entire period of useful service. With the formation of a groove in the tool face, the chips assume a spiral form, either short or long, but of relatively small diameter. When in this state the chip is cooler and no longer tinted, and the tool will continue to cut for the major portion of its service period. As the freshly formed cutting edge begins to break down, the chips acquire an uneven form, are rough on the underside, and once more turn blue.

Life of Turning Tool.—This progress of wear and breakdown appears to apply for heavy cuts and light alike. The time of complete tool breakdown is readily perceptible in the course of heavy cuts, since there will be a swift alteration in the tint of the chips, which take on a rich blue, while the cut shoulder will have a burnished surface. While the general course of events will be similar when light cuts are being taken, it will not be found so easy to decide the exact moment of tool breakdown.

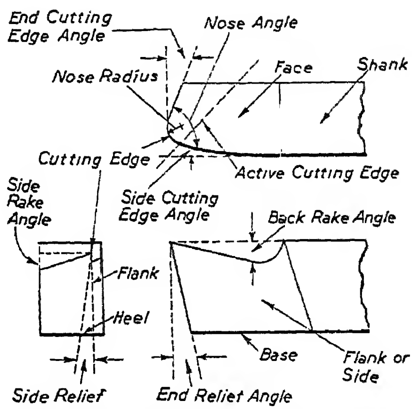


Fig. 1.—Characteristic high-speed-steel cutting tool of solid type.

For any specific steel, tool, and cutting condition the life of a turning tool varies inversely with the cutting speed, as expressed by the equation VT^n equals C, where V is the surface cutting speed in feet per minute, T is the tool life under cut up to the moment of failure measured in minutes, and n is the exponent of T equalling the tangent of the angle of slope of the cutting speed tool-life curve when plotted on log-log paper. C is a constant varying with the particular circumstances, e.g. kind of material, dimensions, form, tool steel, dimension and form of cut, and coolant.

We must now examine the influence of the steel being cut upon machinability. It will be found that this problem has to be considered from many points of view, factors of importance being the analysis of the steel and whether or not it has been designed for free cutting; the methods by which it has been manufactured; the grain size; the method of fabrication; the heat treatment to which it has been subjected; the physical properties of the material; its structure; and lastly, the dimensions of the steel cut.

Carbon-steel Tools.—Carbon steel will cut more readily than most highly alloyed steels, though some of these may be made into relatively free-cutting steels by the introduction of such special alloys as sulphur, lead, selenium, and manganese. When we are dealing with cold-finished bar stock for screw-machine work, it will be found that for the low- and medium-carbon steels the best structure is one of lamellar pearlitic type. With the high-carbon steels, a spheroidised condition will be beneficial in lengthening the period of effective service of the tool. In general, steel manufacturers are in agreement that with ordinary cold-drawn steels maximum machinability is obtained when the elongation of the steel being

cut is from 13 to 16 per cent. in 2 in., with a minimum reduction of area of 40 per cent. If the elongation is allowed to fall below 10 per cent. and the reduction of area below 35 per cent., there is a distinct possibility that the tool will not last so long. In machining steels designed for screwing-machine products, the chips should be small, the surface finish good, and the tool life at high speed satisfactory, but it cannot be said that these three points are readily obtainable *in toto*. Alloy steels susceptible to rapid work-hardening should preferably be hot-rolled and annealed for machining.

The higher the percentage of alloys in the steel being machined, the more advantageous becomes the preliminary annealing or normalising treatment. With carbon case-hardening steels, normalising is less essential, because the steel will machine readily enough when in the hot-worked state. With steels of low alloy content but fine grain and shallow-hardening properties, the normalising temperature should be raised so as to produce the lamellar pearlitic structure already referred to as conducive to good machinability.

In those instances, such as rough turning in the lathe, where surface finish is less vital, it is more advantageous to have low hardness than low ductility. For finishing cuts on nickel-chromium, nickel-chromium-molybdenum, and chromium-vanadium steels, it is advisable not to allow the hardness to exceed 207 Brinell, as even if the steel has the proper pearlitic structure there is more than a likelihood of reduction in tool life.

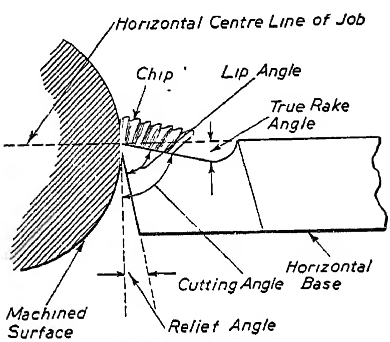


Fig. 2.—A further high-speed-steel cutting tool of solid type.

Fine-grained Steels.—Fine-grained steels such as those of highly ductile type suitable for oil-hardening or case-hardening will respond to heat treatment without excessive distortion, and will produce a fine surface finish, but for heavy cuts it is better to have a less dense or coarser-grained steel. A certain modification of the tool form should be made to suit the grain size.

It is always difficult, if not impossible, to give recommendations of speed and feed for turning and other machining operations, because conditions vary from shop to shop, and too many variable factors enter into the question. However, if steels are machined in turret lathes with correctly formed tools of high-speed steel, and roughing cuts are taken $\frac{1}{16}-\frac{3}{16}$ in. deep with feeds of 0·02–0·06 in., the cutting speeds claimed to produce the best commercial values of tool life are as in the table below:

Type of Material	*Surface ft. per min.*
Alloy steel, in the softened condition	50–60
Alloy steel, heat-treated	25–40
Steel castings	50–60
Hard mild steel	35–60
Medium hard mild steel	60–85
Soft mild steel	100–120
Threading steel	25–40
Annealed tool steel	60–80
Unannealed tool steel	25–35

Sometimes the tools must be ground to give a specific form of job, and this demands lower cutting speeds. The speeds given above can be regarded only as general guides for setting up, and must be varied to suit requirements and shop conditions. By the employment of suitable coolants, it is possible to cut at speeds higher than those above. When the cutting alloys are used for the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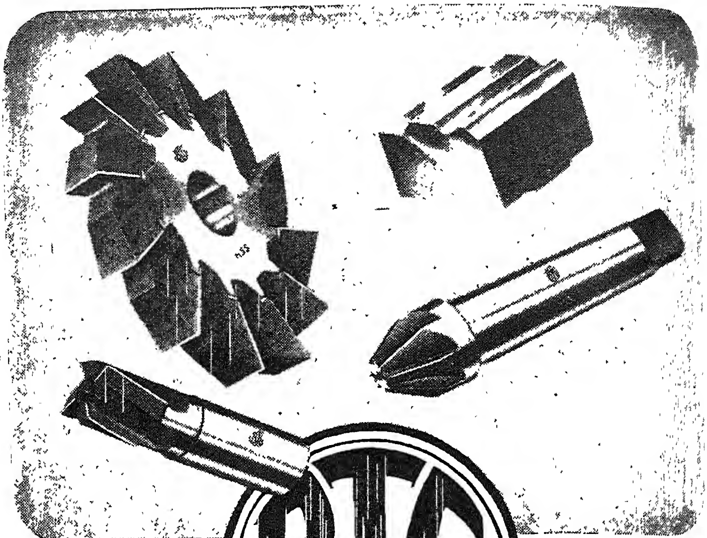

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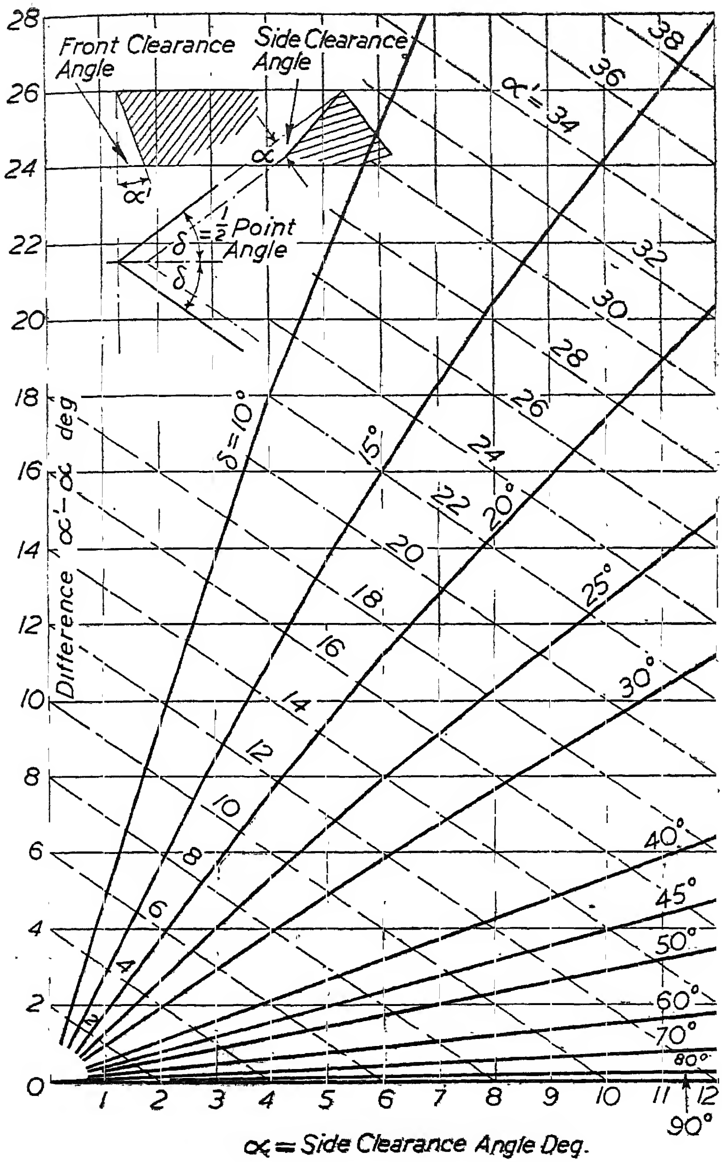


Fig. 3.—Graph showing influence of cutting angles on height adjustment of cutting tools.

cutting tools, e.g. stellite and tungsten- or tantalum-carbide, great increases in speed may be obtained. Thus stellite will enable the above figures to be increased from 25 to 75 per cent., according to the type of steel being machined and the kind of finish required. Tungsten-carbide tools will enable speeds up to 250–300 ft. per min. to be attained if the correct form of tool is used. For machining with carbon-steel tools the above list of speeds must be reduced by one-half.

Bar Stock.—Bar stock for machining in hand and automatic screwing machines needs usually a lighter cut than for turret-lathe work, so that the speeds are increased.

Sulphur and selenium added to steels will raise their machinability. Cold-drawing steel improves its machinability and also brings it closer to size and reduces the amount of surface scale. Hot-rolled bars are not to be compared in machinability with cold-drawn bars. When an alloy steel undergoes extensive work-hardening as a result of the cold-drawing operation, it is usually hot rolled and annealed before being machined. A steel for easy cutting must not only be low in ductility but also avoid work-hardening. The tools must be so ground as to cause the chips to crumble rather than produce long spirals.

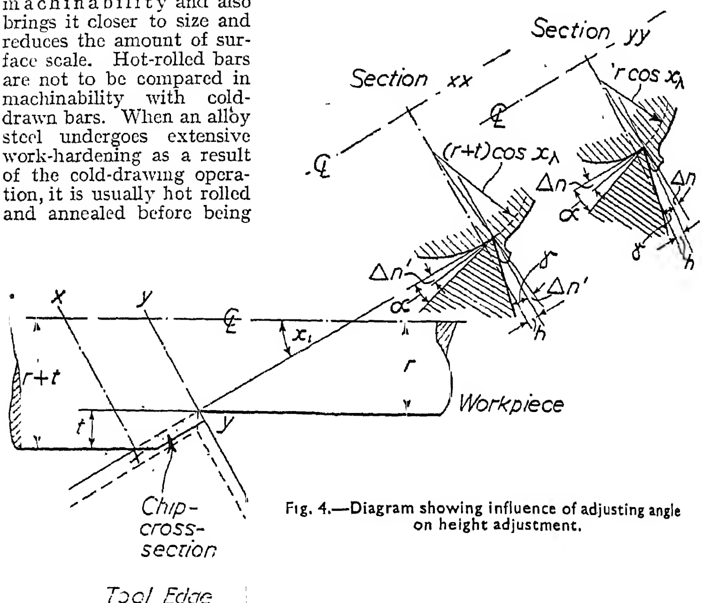
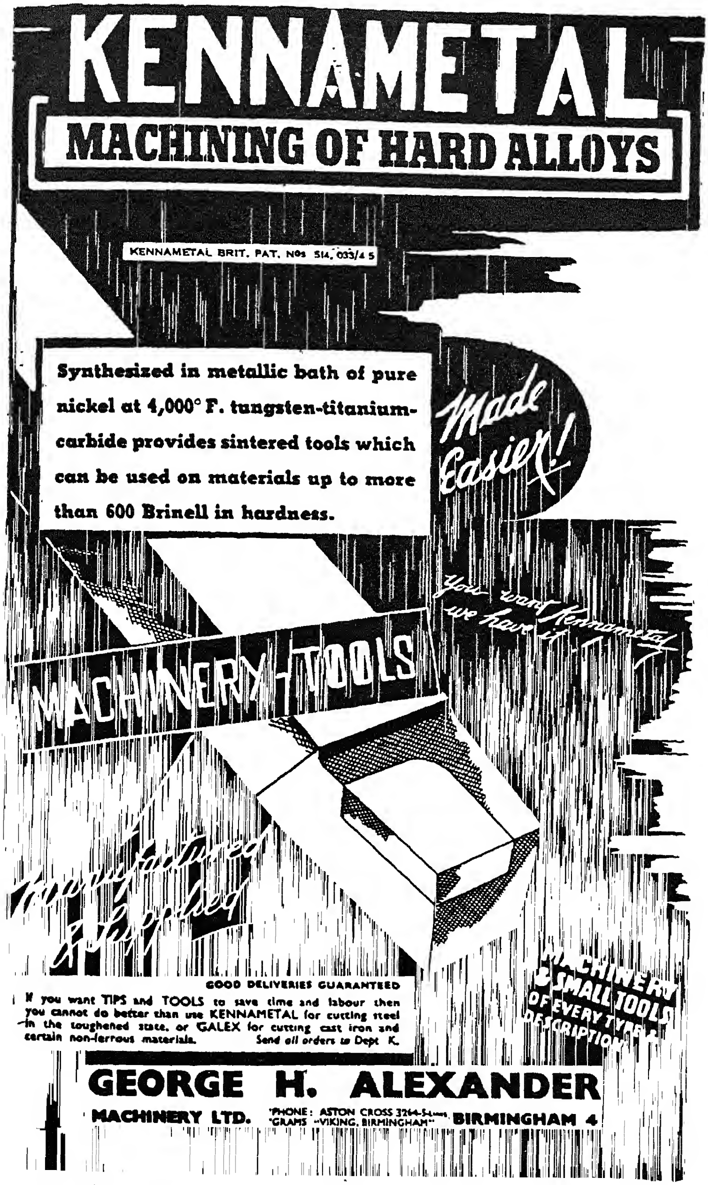


Fig. 4.—Diagram showing influence of adjusting angle on height adjustment.

The efficiency of a cutting tool depends on the length of time per grind it will cut at a certain speed under given conditions (known as tool endurance), on the power it consumes in removing the metal, and on the type of finish it gives. The smaller the cutting angle and the greater the rake, the more effective is the cutting action from the point of view of power consumption. A sharp lip will not cut hard metals for so long a period of time as a blunt lip. The greater the lip angle, the more body of resistance there is to the cutting force, and the more quickly will the heat generated in cutting be dispersed. A tool with large rake will lead the chip to travel over its face with less distortion, and the small-rake tool will force the material off with too great a shear and compression. Tool failure is in the main occasioned by: abrasion on the side or flank under the actual cutting edge; the formation by abrasive action of a groove on its face behind the cutting edge, which gradually extends towards the cutting edge and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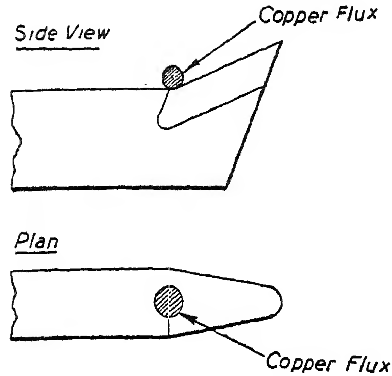


Fig. 5.—A shank ready for tipping. The tip is placed in its seat, and a piece of copper, together with a small quantity of flux, is placed on top of the tip where the joint is effected.

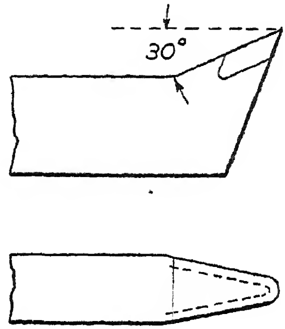


Fig. 6.—A special design of tool for turning commutators, which, of course, contain thin sheets of mica.

causes an unexpected fracture of the latter; a combination of both these causes; flaking or crumbling of the cutting edge; loss of hardness due to the generation of too much heat at the cutting edge.

The first three causes can be regarded as quite normal, and will often be found in carbon tool steels put to work on steel and cast iron. High-speed steels may fail in these three ways when working on cast iron, the second and third types of failure being the more usual.

Tool performance is affected by composition of the tool steel, method of melting and casting, fabrication, heat treatment, physical properties, form of the tool, tool sharpness, structure, and tool setting.

The tools must be so shaped as to suit the metal of which they are composed. Cutting speeds and depth of cut must be such as the particular material of which the tool is made will be capable of giving. Carbon tool steels are to-day employed only for light cuts at low speeds, as in screwing machines on free-machining metals where the tool is thoroughly cooled, or where form tools are kept in stock for occasional employment. Most cutting tools are still of high-speed steel. The 14 per cent. tungsten type is used for ordinary day-to-day jobs where speed of output and depth of cut are not vital factors. The 18 per cent. tungsten steel is the most used for all-round work. For work of harder character at higher speeds, the 22 per cent. tungsten, 5 per cent. cobalt steel is becoming more and more extensively used, while for work no other steel will cut, i.e. the hardest and most difficult materials, the high-cobalt steels are being adopted, and will give as much as 25 per cent. greater production for a number of heavy-duty operations.

Non-ferrous Cutting Alloys.—The non-ferrous cutting alloys, such as stellite and tungsten or tantalum carbide, are cast or sintered to shape and ground. They cannot be forged or heat-treated, and are usually applied by brazing as tips on to shanks of mild steel, or sometimes, in the heavier sections, manganese-chromium steel. They have not the ductility of the high-speed steels, and have their principal field of employment among the materials of abrasive type. Tools made from these cutting alloys should be given less clearance and rake in order to yield a greater lip angle as a backing for the cutting edge. They must be given rigid support in order to prevent any excessive vibration at the cutting edge, or bending, which would cause fracture. In order that the reader may appreciate more fully the technical terms used in connection with ground cutting tools, Fig. 1 is appended, together with Fig. 2, which show a characteristic high-speed-steel cutting tool of solid type.

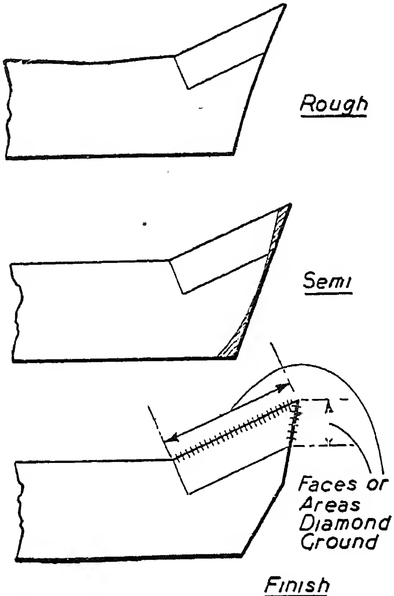


Fig. 7.—When grinding tungsten-carbide tools the shank and the tip should be roughed to slightly more acute angles than are required on the finishing tool. The semi-finishing wheel can be eliminated in the workshop if desired.

Cutting Speed.—According to Boston and Gilbert, for a one-hour tool life the cutting speed is raised by 125 per cent. as the radius of the tool nose is increased from 0–¼ in. By increasing the side cutting angle in the same manner, a considerable increase in cutting speed will be obtained without any sacrifice of tool life. Side-cutting angles over 30 degrees on deep cuts, where deep, thin chips are taken, will often cause chatter, which can sometimes be reduced by altering the coolant, the cutting speed, the dimension or form of the cut, or—better—by lessening the side-cutting edge angle. The speed for a one-hour tool life is raised 55 per cent. as the side-cutting edge angle is raised from 0–60 degrees. The side rake angle likewise gives a higher cutting speed for any specific life of tool, but when machining an annealed nickel steel, maximum speed was attained for a side rake angle of 22 degrees. Nevertheless, a 70 per cent. increase in cutting speed was secured by raising the side rake angle from 0–22 degrees. In machining soft steel, the maximum tool life for a given speed is attained when the tool is given 8 degrees back rake, 22 degrees side rake, 6 degrees clearance, 6 degrees end-cutting edge angle, 45 degrees side-cutting edge angle, and ⅛-in. nose radius. For a steel of harder quality, the side-cutting edge and side rake angles should be decreased.

In taking a cut 0·1 in. in depth, with a feed of 0·0125 in. in a 0·61 per cent. carbon steel of 207 Brinell and 99,000 lb. per sq. in. tensile, with a basic tool having 8 degrees back rake, 14 degrees side rake, 6 degrees end-cutting edge angle, 15 degrees side-cutting edge angle, and $\frac{3}{64}$-in. nose radius, the cutting force varied thus. The nose radius being raised to 0–¼ in., the tangential force remained virtually unaltered at 395 lb. The longitudinal force fell from 185–95 lb., and the radial force was raised from 25–150 lb.

Front and Side Clearance Angles.—Fig. 3 represents the interrelation between front and side clearance angles and the point angle. It permits the solution of every problem which may arise in this connection. A form of diagram was selected to permit those not experienced in trigonometrical calculations to solve these problems in a quick and safe way for any given value, but for the benefit of those knowing trigonometrical relations it may be said that the diagram is based on the formula $\tan \alpha = \tan \alpha' / \sin \delta = \tan \alpha' . \operatorname{cosec} \delta$, with α = side clearance angle, α' = front clearance angle, and $\delta = \frac{1}{2}$ point angle, all in degrees.

The same diagram can be used for determining the interrelation between the rake angles, i.e. γ side rake angle and γ' front rake angle.

The scale for γ is identical with that for α'.

γ' ,, ,, ,, ,, α.

$\gamma - \gamma'$,, ,, ,, ,, $\alpha' - \alpha$.

In drawings of tools generally only the front clearance angle and the point angle are given, thus leaving it to the toolmakers to find the side clearance angle which is

necessary for grinding. Some toolmakers believed that both angles are the same, but experience soon told them that there is a difference, which increases with smaller point angle.

The base line contains the side clearance angle α from 0 to 12 deg., the ordinate the difference between front and side clearance angles ($\alpha' - \alpha$), the former being always bigger than the latter. Two series of curves are introduced; in full-line curves for the $\frac{1}{2}$ point angle δ from 10 to 90 deg., which above $\delta = 30$ deg. are almost straight lines, and dotted lines of $\alpha' =$ constant, from 2 to 38 deg.

For instance, a chisel edge has to be produced with 120-deg. included angle and 10-deg. front clearance: the included angle between the faces is required, i.e. $\delta = 60$ deg. and $\alpha' = 10$ deg. We find in the diagram the intersection point between $\delta = 60$ deg. and $\alpha' = 10$ deg., giving 8 deg. 44 min.; the included angle between the surfaces is 81 deg. 16 min. A tool has to be produced with side clearance of 7 deg. and a $\frac{1}{2}$ point angle of 30 deg., i.e. $\alpha = 7$ deg. and $\delta = 30$ deg. The intersection of the vertical line through $\alpha = 7$ deg. with the full line for $\delta = 30$ deg. gives $\alpha' - \alpha = 6$ deg. 45 min., thus $\alpha' = 13$ deg. 45 min.

Since the diagram shows that the curves for δ larger than 30 deg. are practically straight lines, it may be useful to memorise the following values in order to make calculations without the use of the diagram or logarithmic tables; it may be mentioned that these values are only approximations:

Half Point Angle	*Degrees*							
	30	40	45	50	60	70	80	90
Ratio α'/α	1·94	1·54	1·4	1·29	1·15	1·07	1·015	1
,, α/α'	0·515	0·649	0·714	0·775	0·870	0·935	0·982	1

For instance, for $\delta = 45$ deg. and $\alpha' = 7$ deg. 45 min., we obtain $\alpha = 5{\cdot}525 =$ 5 deg. 31·5 min.

In the case of a tool with a radius, the size of which is kept throughout the height of tool-bit, the relations between front clearance angle and side clearance angle remain apparently the same as for a sharp-pointed tool nose. Only the side clearance angle changes along the rounded rose continually from α' to α; for instance, for a tangent under 30 deg., i.e. point angle of $\delta = 60$ deg., the side clearance angle is according to this value. (See also Fig. 4.)

When setting the tool point above or below the centre height without changing the direction of the toolholder, the cutting angles become changed, i.e. in the case of setting above centre height the rake angle is increased and the clearance angle reduced by the same amount, and vice versa when lowering the tool edge below centre position. The approximate relation for the angle difference is $\Delta = 115h/\mathrm{D}$ in deg. with h height above (or below) centre line, D diameter of the work-piece to be machined, being obtained from the exact relation $\sin \Delta = h/\mathrm{D}$. It was later found that the front adjusting angle x_1 should preferably be included, leading to the improved approximate relation

$$\Delta_n = 115\, h.\cos x_1/\mathrm{D} \text{ respectively.}$$
$$\Delta_n' = 115\, h.\cos x_1/(\mathrm{D} + 2t).$$

This new formula is based on the following considerations: The actual cutting process takes place along a cone surface (exactly a hyperboloid surface when the tool edge is not adjusted on centre height) with an included half-angle corresponding to the adjusting angle x_1 (see Fig. 4). Only in the plane perpendicular to the cone surface the actual cutting angles are present, whereby the work-piece does not present a true circle towards the tool edge, but a cone section, i.e. an ellipse. With r the finished half-diameter of the work-piece, the radius of curvature of the section ellipse becomes $r/\cos x_1$. This radius therefore controls the angles of the cutting edge in the case of height adjustment. Therefore the difference angle becomes $\sin \Delta_n = h.\cos x_1/r$. This value varies along the cutting edges with the actual radius r. If we understand under r the finished radius of the work-piece we obtain a maximum value for Δ at the point of the tool $\sin \Delta_n = h.\cos x_1/r$; and a smaller value: $\sin \Delta_n' = h.\cos x_1/(r + t)$ for

the outside diameter; the difference angle varies along the tool edge from Δ_n to Δ_n'. By replacing the sine by the radians and converting the radians into degrees the above-mentioned approximate formulæ may be derived, which are accurate enough for all practical cases.

Two examples will demonstrate the application and the accuracy of these formulæ: Given D = 5·0 in., h = 0·04 in., t = 0·15 in., x_1 = 45 deg.; therefore, cos x_1 = 0·707. Approximate calculation:

Usual formula: $$\Delta = 115 . \frac{0{\cdot}04}{5{\cdot}0} = 0{\cdot}92\,;\ \Delta = 55^\circ.$$

Improved formula: $$\Delta_n = 115 . \frac{0{\cdot}04 . 0{\cdot}707}{5{\cdot}0} = 0{\cdot}65\,;\ \Delta_n = 39^\circ.$$

$$\Delta_n' = 115 . \frac{0{\cdot}04 . 0{\cdot}707}{5{\cdot}3} = 0{\cdot}612\,;\ \Delta_n = 36^\circ\ 8'.$$

Exact calculation:

$$\text{from } \sin \Delta = \frac{0{\cdot}04}{2{\cdot}5} = 0{\cdot}016\,;\ \Delta = 55^\circ.$$

$$\text{from } \sin \Delta_n = \frac{0{\cdot}04 . 0{\cdot}707}{2{\cdot}5} = 0{\cdot}0113\,;\ \Delta_n = 39^\circ.$$

$$\text{from } \sin \Delta_n' = \frac{0{\cdot}04 . 0{\cdot}707}{2{\cdot}65} = 0{\cdot}0107\,;\ \Delta_n' = 36^\circ\ 8'.$$

The comparison shows clearly that the approximate formulæ are supplying almost identical results as the exact calculation. Further, the differences between the old value and the new values are quite distinctive; the difference $\Delta_n - \Delta_n'$ shows the variation of the angle along the cutting edge.

Cemented Carbides.—No formal list of standard properties of the cemented carbides can be drawn up, because there are wide differences in composition, and the way in which the carbide is prepared also exercises a considerable influence on properties. Density and other properties are largely conditioned by the percentage of cobalt employed as a binder. Density gradually declines as the cobalt content rises from 3 to 20 per cent. The modulus of rupture as established by transverse strength in tons per square inch rises sharply with increasing cobalt content up to 13 per cent. cobalt. There is a slight falling off in hardness up to 13 per cent. cobalt. Electrical resistance appears to fluctuate, since it falls as the cobalt rises to 6 per cent., increases at 9 per cent., falls again at 13 per cent., and rises sharply at 20 per cent. The temperature coefficient of resistance slowly falls up to 20 per cent. cobalt, as does the compressive strength up to 13 per cent. A tungsten carbide with a 13 per cent. cobalt content appears to have a higher elastic modulus than that of any other known substance, being in the region of 34,360 tons per sq. in. The thermal conductivity has been fixed at 0·652 watts per cm. per sec. per deg. C. with a deviation of plus or minus 0·025.

Tungsten and Tantalum Carbide.—In the main, tungsten carbide appears to be more popular in this country and on the Continent, whereas in the United States there are many advocates of tantalum and titanium carbides.

In general, the only points in which tantalum carbide can claim a certain superiority over tungsten carbide appear to be in ability to withstand some forms of corrosion more effectively, and a slightly less generation of heat during cutting, with a consequent minimisation of craters on the cutting edge. The titanium compositions are primarily tungsten carbide with a titanium addition designed to facilitate the cutting of steel with this material.

For machining gunmetal and non-ferrous materials generally, as well as cast iron, the standard shapes as shown in the makers' catalogues are recommended. For machining gunmetal, tools without top rake, i.e. flat on top, with 10-deg. front clearance, are advised. For machining cast iron, tools with 3-deg., 8-deg., or 13-deg. rake are standard, whichever is preferred. If the user is in doubt which is the better for workshop use, the 8-deg. is recommended, because it is invariably cheaper and easier to de-rake a tool slightly than to carry out the reverse operation. As an example of what can be done with these tools, it may be

mentioned that $\frac{5}{32}$ in. of material was removed from tough bronze forged rings at 520 ft. a minute, with a feed of 200. The rings finished to within 0·005-in. tolerance one cut, and 200 were machined before the tool needed to be reground. In another instance hard bronze trolley wheels were machined, taking $\frac{1}{8}$-in. cut at 400 ft. a minute, with 200 feed, the tool doing 2500 cuts without needing to be reground.

For Individual Needs.—Many large works adopt the principle of buying the tips and putting them on in their own works, in such a way as to suit their individual needs. A little study of the subject will reveal that a particular standard tip can be attached to the shank in various ways, resulting in different designs of tools.

The normal procedure used in brazing tungsten carbide to the shanks is to grind the tips on those areas where brazing is to take place, so as to eliminate any roughness that might interfere with the correct bedding down of the tip in its seat. When the shanks have been properly recessed to take the specific form of tip desired, and both tip and shank have been wiped clean and free from dirt, grease, oil, etc., the tip is placed in its seat and a piece of copper, together with a small quantity of flux, placed on top of the tip, where the joint is effected, as in Fig. 5.

The pieces of copper are best prepared by either cropping a piece of rod or wire to short lengths, or, alternatively, placing a piece of plate copper in the shaping machine and taking fairly heavy cuts, so as to produce a conveniently sized chip. The flux consists of burnt borax mixed with distilled water into a paste of about the consistency of ordinary bricklayer's mortar. The complete assembly is then placed in the preheating chamber of the furnace, running at about 800° C., and the tools preheated. After this operation, they are transferred to the high-temperature chamber, which, for convenience, should be at 1100–1150° C., i.e. a temperature slightly in excess of the melting-point of copper, so as to facilitate the brazing and carry the process out more quickly and efficiently. The type of furnace normally used is a high-speed steel-tool-hardening furnace, but it is advisable to employ a non-oxidising flame as far as possible.

Fitting Tips.—When the copper begins to run the tool is withdrawn from the furnace, the tip is pressed lightly but firmly into the correct position, and the whole then placed in powdered charcoal to ensure that cooling is gradual. This slow cooling is essential in order to prevent cracking. An alternative method is to braze the tips on with Sifbronze, the heat in this instance being applied by an oxy-acetylene torch. This method is specially suitable for small tools up to approximately 1½ in. by 1 in.

An interesting practical problem with these tools is the turning of commutators, which, of course, contain thin sheets of mica. The normal method is to rough off with a tungsten-carbide tool of special design, as shown in Fig. 6. This design is, however, not advised for finishing, which should be done with diamond-tipped tools.

A point to be noted is that tungsten-carbide tools are not recommended for planing and shaping work unless the clapper box has an automatic or power device for lifting the tool clear of the work on the return stroke.

The conditions under which grinding operations on these tools are performed, and the types of wheels used, have a great influence on the grit and grade recommended. Silicon-carbide wheels are probably the best for roughing and semi-finishing. For finishing, diamond wheels are advantageous. For roughing, wheels 20-in. diameter by 2½ in. in width and of plain cylindrical type are advised. For semi-finishing, wheels 20-in. diameter by 4 in. wide, of double-sided cup type, are recommended. For finishing, a diamond grinding wheel 6-in. diameter by 1½ in. wide is best. The wheels should be employed with a plentiful supply of coolant, and the roughing and semi-finishing run at about 4500–5000 surface ft. per min. The diamond finishing wheels run at about 9000 surface ft. per min.

In general, heavy pressure should not be used, but only light pressure. The wheel should be allowed to do its work without the generation of a great deal of heat, as this is likely to crack the tips. Under the first operation, the shank and the tip should be roughed to slightly more acute angles than are required on the finishing tool, as shown in Fig. 7. The semi-finishing wheel can, if desired, be eliminated in a workshop, because its main purpose is to provide a high finish,

such as is necessary on an article intended for sale. While this is less important in ordinary workshops, the retention of the semi-finish is advised because it ensures less risk that the operator will try to do too much with the grinding wheel. The semi-finishing wheel is used to shape the tools to the necessary angles, shapes, etc., leaving only a small allowance for the diamond finish.

The Diamond Wheel.—The diamond wheel cuts extremely freely, is very cool, and has no difficulty in producing flat surfaces free from round edges. A tool so finished will give longer service life than one more roughly ground, so that the user is recompensed for the additional pains taken to secure a good finish in grinding.

Aircraft bolts of S.11 steel can be reduced with tungsten-carbide tools of normal grade running at a speed of 180 ft. per min. with feed of 240 cuts per inch. These bolts are reduced in one cut from 1-in. down to $\frac{7}{8}$-in., $\frac{3}{4}$-in., $\frac{5}{8}$-in., and $\frac{1}{2}$-in. diameter, plus or minus 0·001 in., on a capstan lathe. The bolts are checked with a ring gauge and are produced with a mirror finish.

Screw-cutting tungsten-carbide tools are obtainable, but actually screw cutting is a slow-speed operation, which scarcely justifies the expense of these costly tools, while in no circumstances should tungsten carbide be used for cutting threads in steel.

Chromium cast iron can be cut with tungsten-carbide tools, using $3\frac{1}{2}$ deg. top rake, roughing being done at 100–200 r.p.m. and finishing at 200–400 r.p.m. The feed should be $\frac{1}{64}$ in. to $\frac{1}{32}$ in., or more, according to conditions. Nickel cast iron can also be successfully machined by these tools. In one instance, the large bore of brake drums for automobiles was finished at a speed of 316 ft. per minute, with approximately 80 cuts per inch. The machines used were modern semi-automatic chucking machines.

Care of Carbide Tools.—Great attention must be paid to the proper treatment of carbide tools, which must never be allowed to fall or be struck with a hammer in setting up. When setting up, the minimum amount of overhang should be allowed, so as to prevent stresses the material is not adapted to withstand. The tool should not be too small for the job, and a modern, well-designed and constructed toolholder in which the tool can bed down horizontally is advisable. The tools should be positioned so that they cut on the centre line of the work, and the cut should never be deeper than the tip length. Actually the depth of cut is usually controlled by the machine capacity.

The British practice is to supply these tools in three distinct grades. The first or normal grade is usually supplied unless the customer specifies to the contrary. It is designed for use on cast iron and non-ferrous materials generally. The second, or chill grade, is for use on chilled cast-iron rolls, and in some instances on brass. The third, or steel grade, is for use on steel in certain special operations only. In this connection, the advice of the manufacturer should always be taken before this grade is ordered, as there are many pitfalls in the machining of steel with tungsten carbide which will be avoided by this means.

When ordering these tools, it is advisable to give the manufacturer's tool number, and to indicate clearly whether the complete tool, or only the tip, is required. The material on which the tools are to work should be stated and the cutting rake required mentioned. If tools of special form are desired, it is a good plan to send a drawing with the order or inquiry.

Feed.—It is most important that there should be no irregularity in the feed, and that there should be no chatter or vibration in either the machine or the part being machined. Finally, there must be no end movement or lift in the main spindle bearings, while the driving belt or motor must give enough power without any slipping of the belt or clutch.

Tungsten carbide cannot be forged to any particular shape, so that once the tip is made the only manner in which its form can be modified is by grinding.

REAMERS

Hand Reamers.—These are to be had with straight or spiral teeth. In order to facilitate the entry into a hole, the end of the toothed portion is tapered. This taper is usually of the order of about 1 degree a side, and extends to a distance equal to one and a half times the diameter. While suited to reaming out bushings or like objects, where the reamer can pass right through the job, a bottoming reamer having no lead must be used to follow up where a blind hole has to be dealt with.

Most straight-toothed reamers have teeth unevenly spaced, the object of this being to prevent chattering. The teeth are relieved, but a narrow " land " is left along the parallel portion, and although the relief on the lead may be stoned up, any attempt at sharpening generally should be confined to stoning the fronts of the teeth. Great care should be taken with the storage of reamers, as they will quickly become dull if allowed to rub together in a box. To secure the best results from a hand reamer, leave as little metal as possible for it to remove, and also feed it into the work at an even rate per revolution. This is not always an easy matter, and some hand reamers have a threaded lead, which pulls the reamer into the hole at a definite rate of feed, a feature offering a marked advantage in use on phosphor-bronze.

Machine Reamers.—Reamers intended for machine use may differ from hand reamers only so far as the shank is concerned. There are, however, types which are widely different. Shell reamers may be regarded as the fluted portion of a short reamer. The lead is at an angle of approximately 45 degrees on the front of the teeth. A hole through the centre of the reamer accommodates a separate shank, the drive being taken by a flat cotter. Rose shell reamers differ only as regards the arrangement of the teeth. In this instance, the cutting takes place on the front, the body being fluted to admit lubricant. The land between each flute is extremely wide, and therefore no cutting action can take place. The purpose of this class of reamer is to remove a lot of metal, such as enlarging a hole. Once the reamer has started truly, it must continue so on account of the guide afforded by the cylindrical portion. An ordinary reamer having narrow lands would tend to follow any irregularities in the cored hole.

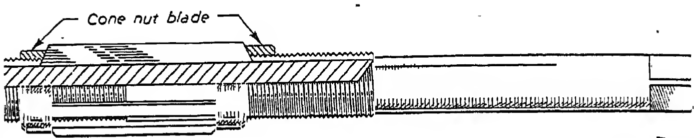
Expanding Reamers.—The reamers so far dealt with are only capable of producing holes equal in diameter to the nominal size. A solid reamer that is sharp can be made to cut a few thousandths oversize by inserting a strip of foil between one of the teeth and the work. As the reamer is fed in, this has the effect of forcing the opposing teeth over to one side of the hole. This method cannot be relied upon with any degree of certainty, and the surest method is to use a reamer of correct diameter. Where the hole required happens to be an odd size, that is, not to a fraction of $\frac{1}{64}$ in. or to an even millimetre, a special reamer will be required. This is quite a practical proposition where such a tool will be constantly required, but for occasional use an adjustable reamer will suit the purpose better.

There is one type of reamer of American origin which is similar in appearance to a solid reamer, with the exception that a short portion of the blank is left unfluted at the bottom. This short portion is a few thousandths smaller than the body of the reamer, and acts as a pilot. A hole is drilled up the body from the pilot, extending beyond the end of the flutes, and a counterbored hole terminates in a slow taper half-way up the flutes. Three equally-spaced narrow slots are cut at the roots of the teeth in the centre hole, the extent of the slots being confined to the toothed portion. The counterbored hole is tapped at the mouth, and the adjustment is effected by means of a screwed taper plug. It will thus be apparent that the slots are opened, causing the reamer to become slightly barrel shaped, and therefore, on account of the liability of the reamer to break if the screw is forced in too far, the range of adjustment is limited to a comparatively small amount. As recommended by the manufacturers, the following limits of expansion should not be exceeded: for reamers $\frac{1}{4}$–$\frac{9}{16}$ in. in diameter, plus 0·005 in.; $\frac{5}{8}$–$\frac{13}{16}$ in., plus 0·008 in., and $\frac{7}{8}$–1 in., plus 0·010 in.

Another similar type of reamer having a narrow range of adjustments is

extended for machine use. In this the fluted portion is short, and is expanded by means of a cone bolt operating on the front end. The slots in this instance are carried out to the end, and therefore the greatest expansion takes place on the front end.

Inserted Blade Types.—Adjustable reamers of this type have a much greater range of adjustment. That shown in Fig. 1 is made with both straight and helical blades. Reference to the part-section view should make the construction clear, but briefly this is as follows: the body, made of good-quality alloy steel, is turned integral with the shank, and the screwed portions accommodate female coned nuts. Equally spaced slots are milled in the body to receive the blades, and the bottoms of these slots taper upwards towards the shank. The blades fit neatly into the slots, the ends being shaped to suit the conical faces in the nuts; incidentally, they are all exactly the same length. When the nuts are locked, the blades are forced on the bottom of the slots and held secure. When in the position shown in the sketch, the reamer blades are at their minimum diameter. By slackening the back nut and tightening the front one, the blades are forced upwards along the tapering slots, thus causing the cutting edges to increase in diameter. The smallest sizes are provided with four blades and the others with six. Thus it is an easy matter to set the blades with the aid of a micrometer. As an indication of the range of sizes covered, it may be mentioned that eleven reamers cover all sizes from $\frac{3}{8}$ to $1\frac{1}{16}$ in. The total expansion on each side of the three lesser sizes is $\frac{1}{32}$ in., but as the diameter increases, so does the amount of adjustment: the largest reamer mentioned expands from $\frac{15}{16}$ to $1\frac{1}{16}$ in.



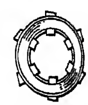


Fig. 1.—An adjustable reamer with both straight and helical blades.

On account of the method of construction, the maximum size can be conveniently increased by inserting a strip of foil or tin underneath each blade. Spare blades are obtainable when required; these being supplied in sets of four or six, as the case may be. One drawback to this particular pattern is that it is unsuitable for use in blind holes. This objection is overcome by the design of the "Vickers" adjustable reamer illustrated in Fig. 1. Here the blades slide outwards, and a micrometer adjustment is afforded by graduations on the head of the centre screw. Fig. 1 shows a longitudinal section; notice the shape of the blades. The locknut is first released and the cone bolt screwed in by means of a special key to effect adjustment. The cone nut holds the blades in position, bearing being taken on both ends of the central cone; again the blades are renewable.

These reamers run from $\frac{5}{8}$-in. diameter upwards, this size being capable of expanding 0·014 in. A separate shank is required as with shell reamers, the drive between being taken by a cotter.

Taper Reamers.—Solid taper reamers are available in Morse and Brown & Sharpe tapers; as are also standard taper-pin reamers, having a standard taper of $\frac{1}{4}$ in. per foot, and arranged in a series so that a continuous taper is formed, with a margin for overlap by the set of reamers. Thus the large end of the reamer is greater in diameter than the small end of the next size in the series. Such reamers may be marked in fractions of an inch to correspond to the nominal diameter of the taper pin, or 000, 00, 0, 1, 2, etc., from small to large. In use, taper-pin reamers require raising occasionally to break the chips in long holes. This prevents gapping the flutes.

Spiral-fluted Taper Reamer.—The only special difficulty that may be encountered in making a spiral-fluted *taper* reamer lies in the variation of spiral

angle from end to end because of the difference in diameter. The procedure is to assume a suitable spiral angle at the half-way section and then to calculate the differences between this and the spiral angles at the ends.

Assuming the angle to be 6 degrees 30 minutes, diameter of small end $1\frac{9}{16}$ in., diameter of large end $2\frac{29}{32}$ in., the diameter at the half-way section is

$$\frac{1\cdot563 + 2\cdot906}{2} = 2\cdot235 \text{ in.}$$

Assuming a spiral angle of 5 degrees at this section:

$$\begin{aligned}\text{Lead} &= 3\cdot1416 \times \text{diameter} \times \text{cotangent of spiral angle}\\ &= 3\cdot1416 \times 2\cdot235 \times 11\cdot43 = 80\cdot4, \text{ say } 80 \text{ in.}\end{aligned}$$

At 2·906-in. dia.

$$\tan \text{spiral angle} = \frac{3\cdot1416 \times \text{dia.}}{\text{Lead}} = \frac{3\cdot1416 \times 2\cdot906}{80} = 0\cdot114.$$

$$\text{Spiral angle} = 6^\circ\ 30'.$$

At 1·563-in. dia.

$$\tan \text{spiral angle} = \frac{3\cdot1416 \times 1\cdot563}{80} = 0\cdot0613.$$

$$\text{Spiral angle} = 3^\circ\ 32'.$$

Thus the spiral angle does not change by more than 1 degree 30 minutes from the mean value, and this difference is negligible.

The milling-machine table is set at 5 degrees to the normal position, and the dividing head and tailstock mounted so that the angle between the centre line of the work and the surface of the table is the half-angle of the taper required. When the work is mounted between centres the high points should all give the same reading on a dial indicator carried on a stand resting on the table. Alternatively, the check may be made by using a height gauge.

A suitable fluting cutter should then be mounted on the arbor. The table should be set so that the half-way section of the work lies under the centre line of the arbor; the setting need not be specially accurate. The cutter is set in motion and the table raised until the cutter almost touches the work.

The table is moved backwards and forwards along the cross-slide to make sure of getting the "high-spot." The table is raised slightly and the cross-movement repeated until a light cut is made. The cross-slide is locked in the position at which this cut is made.

The dividing head is then connected to the table feed screw by gears which give a left-hand lead of 80 in. The table is wound horizontally until the cutter clears the end of the work, when the table is raised through a distance equal to the depth of flute required.

The formula for the lead gears depends on the lead of the feed screw and should be included among the operating data of the machine. It may, for example, be:

$$\frac{\text{Product of teeth in driving gears}}{\text{Product of teeth in driven gears}} = \frac{40 \times \text{lead of feed screw}}{\text{Lead of work}}.$$

For a long lead, such as 80 in., the table feed screw is the "driver," as it will need to make a larger number of revolutions than does the handle of the dividing head.

If the lead of the feed screw (i.e. its pitch if, as usual, it has a single thread) is 0·25 in., the formula becomes:

$$\frac{\text{Product of teeth in driving gears}}{\text{Product of teeth in driven gears}} = \frac{40 \times 0\cdot25}{80} = \frac{1}{8}.$$

Suitable gears would be $\frac{20}{80} \times \frac{25}{50}$.

In no case need there be any difficulty in selecting change gears, as there is no objection to a lead somewhat different from the intended value. The nearest convenient lead may be used.

In indexing for the different flutes, it is desirable to avoid exactly equal spacing.

Circular Saws.—For 26-in.-diameter circular saws for cutting mild-steel shafts up to 6-in. diameter, a saw $\frac{1}{4}$ in. thick with a gullet tooth and a $\frac{1}{2}$-in. pitch is advisable. For 30-in.-diameter saws for general rough work in the forge, the saw should be $\frac{5}{16}$ in. with a handsaw tooth $\frac{3}{4}$ in. full. For cutting tool steel up to 5-in. diameter or 12-in. by 3-in. section, a 26-in.-diameter saw is required, $\frac{1}{4}$ in. thick, handsaw tooth $\frac{3}{8}$ in. full. For cutting cast steel, such as electric-motor yokes, a 26-in.-diameter saw, $\frac{1}{4}$-in. gullet tooth, $\frac{1}{2}$ in. full, is recommended. In each case a bright-finished saw is advisable.

Necessary Power.—The approximate power required to drive circular wood saws when the timber is being fed by hand is 1–$1\frac{1}{4}$ b.h.p. per inch depth of cut. For cutting lead pipes from 2–7-in. diameter, a saw 18 in. in diameter by 14 gauge thick with set teeth is recommended, and should be run at a speed between 500 and 600 r.p.m. For cutting cold main-line steel rails, a special alloy-steel saw 22-in. diameter by $\frac{1}{4}$ in. thick is recommended, and should be run at about 9–12 r.p.m. with a feed of about $\frac{5}{8}$–$\frac{3}{4}$-in. traverse per minute.

In slotting $\frac{1}{8}$ square brass hollow ferrules for condensers with a $2\frac{1}{2}$–5-in.-diameter saw, the best pitch of teeth is about $\frac{1}{8}$ in. If a larger tooth were used, the material would probably drag and pull in, and the clean cut and finish necessary in cutting out a slot would not be obtained.

Cutting mild-steel sections, such as joists, channels, tees, bars, etc., in the cold state requires saws of diameters ranging from 24–42-in. diameter. The peripheral speeds for all these sizes for cutting cold should be 60–65 ft. per min. on mild steel, and 40–45 ft. per min. on hard steel, with $\frac{5}{8}$–$\frac{3}{4}$-in. traverse feed.

For hot-sawing billets from 6–8-in. diameter a 60-in. saw is required, driven by a 150-h.p. motor running at 720 r.p.m. The motor should be coupled directly to the saw, and the power actually taken will be 100–120 kilowatts.

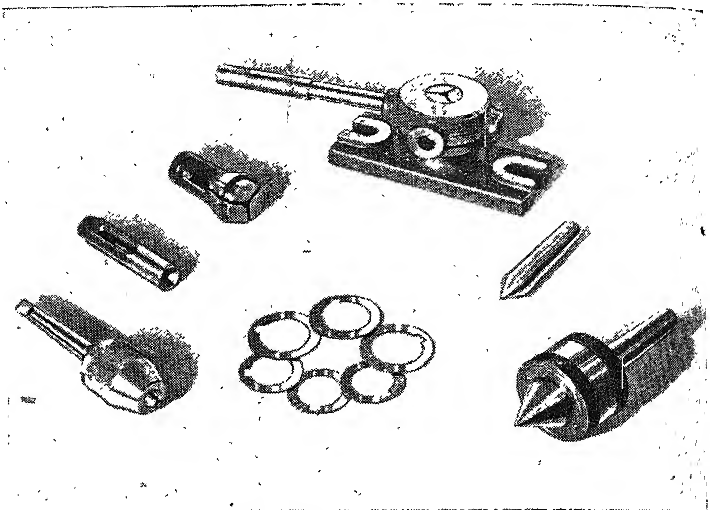
Operational Notes.—The following points should be carefully noted. The tooth most suitable for sawing thin sections, flat bars, etc., is not intended for use on solids. Each type of sawing should be done with a saw made for the purpose, i.e. with a smaller pattern and pitch of tooth in the first case and a larger in the second. The saw should be run at feed and speed according to the work, and should be fed gradually into the cut, not forced in immediately. It should be run through a trough of soapy water. The bearings of the sawing machine should be periodically overhauled, because if worn and loose they may break the saw.

Circular hot saws are often used with a tooth quite unsuitable for sawing hot metal. Although saws of this type are designed to saw metal in the hot state, the metal is actually often black hot or even colder. Hot saws should never be kept at work till their teeth are half worn away. If cracks occur, as is almost inevitable in view of the fluctuating temperatures to which the saw is subjected, they should be treated as follows. If vertical with the teeth, they are not dangerous, and a hole of small diameter should be bored at the base to prevent them from extending. If horizontal to the teeth they are very dangerous, since they may connect up with other cracks and cause a large piece of the saw to come away, with possibly serious results. Such saws should be taken out and sent back to the maker to be cut down and retoothed, if worth the expense; this is a point which can be decided only by the user.

Circular wood saws should frequently be sent back for rehammering.

Bandsaws.—The narrow bandsaws used in contour sawing are made in three standard thicknesses, according to their width, these being 0·025 in., 0·032 in., and 0·035 in. Furthermore, the back edge, i.e. the opposite edge to the toothed edge, is annealed. Only the teeth are hardened, the hardness extending only as far as their bases, and it is not feasible either to reset or to resharpen the teeth of the saws once they have become worn as a result of use. The width of the saw is decided by the feed and the curvature to be cut. It is always advisable to use the widest possible blade. The table on p. 1140 may be used as a guide in this respect:


FOR ALL-ROUND EFFICIENCY
SPEARSEG
REGD.
METAL CUTTING
SEGMENTAL SAWS
SPEAR & JACKSON LIMITED • SHEFFIELD
SAW MAKERS FOR OVER 160 YEARS
SS26



Material to be Cut	*Saw Velocity (feet per minute)*		
	$\frac{1}{16}$–$\frac{1}{4}$ *in.*	$\frac{1}{4}$–1 *in.*	1 *in. and over*
Carbon, 1010–1095	305–220	220–195	195–150
Free cutting, 1112–1340	—	250–200	200
Manganese, T1330–T1350	200–170	170–145	145–90
Nickel, 2015–2515	210–150	150–125	125–95
Nickel-chromium, 3115–3450	125–105	105–75	75–50
Molybdenum, 4130–4820	200–125	125–100	100–70
Chromium, 5120–52100	140–125	125–105	105–80
Chromium-vanadium, 6115–6195	175–100	100–80	80–60
Tungsten, 71360–7260	200–125	125–95	95–70
Silicon-manganese, 9255–9260	205–150	150–100	100–55
18-8 stainless, 30905–30915	100–75	75–50	50
Other stainless, 51210–51710	100–75	75	75–50
High speed	145–125	125–95	95–70
Tool (oil hard)	190–150	150–120	120–75
Tool (air hard)	150–125	125–95	95–65
Drill rod	—	125–90	—
Armour plate	170–125	125–85	85–55
Iron	—	150–125	125–50
Semi steel	—	225–200	200–100
Nickel iron	200–150	150–100	100–50
Malleable iron	210–180	180–155	155–125
Swedish iron	210–160	160–110	110–75
Mechanite	150–100	100–80	80–55
Copper (soft)	1200–800	800–600	600–200
Copper (cold rolled)	1100–700	700–500	500–200
Brass (cast)	1000–400	400–250	250–150
Brass (soft)	1000–450	450–325	325–250
Brass (navy rolled)	315–255	255–230	230–200
Bronze (cast)	800–300	300–210	210–150
Bronze (soft)	1000–425	425–300	300–200
Manganese bronze	610–360	360–225	225–185
Nickel-aluminium bronze	500–280	280–225	225–190
Beryllium copper	500–390	390–260	260–200
Phosphor-bronze	600–300	300–200	200–140
Copper silicon	385–200	200–150	150–110
Aluminium (pure, rolled, or forged	1400–1175	1175–980	980–625
Duralumin 14st	1400–1150	1150–975	975–275
Duralumin 17st	1400–1200	1200–1000	1000–250
Aluminium (cast)	1000–600	600–400	400–200
Nickel (cold rolled)	150–105	105–80	80–55
Monel metal	190–125	125–100	100–60
Nickel silver	310–255	255–200	200–110
Babbitt lead	1000–450	450–300	300–250
Silver	340–250	250–200	200–150
Dow metal	820–360	360–250	250–190
Gunite castings	300–175	175–125	125–100
Mica	340–235	235–190	190–14
Porcelain	200–150	—	—
Asbestos	1400–1000	1000–500	500–300
Builders' board	1500–1000	1000–600	600–200
Fibre	1020–600	600–410	410–175
Hard rubber	310–205	205–150	150–120
Slate	290–200	200–145	145–95
Bakelite	1400–1180	1180–810	810–400
Neoprene	1400–1000	1000–420	420–290

Bandsaw Width in Inches	*Minimum Radii Cut (with heavy set saws)*
$\frac{1}{16}$	90°
$\frac{3}{32}$	$\frac{1}{16}$ in.
$\frac{1}{8}$	$\frac{1}{8}$,,
$\frac{3}{16}$	$\frac{5}{16}$,,
$\frac{1}{4}$	$\frac{5}{8}$,,
$\frac{3}{8}$	$1\frac{7}{16}$,,
$\frac{1}{2}$	$2\frac{1}{2}$,,

There are two thicknesses of set. The first is termed the light set, i.e. 0·032-in. width of teeth (approximately 0·004-in. set on each side). The light set is employed as a rule for the type of work that does not present a considerable number of curves and is in itself of considerable dimensions and weight. On such work the light set produces the least amount of vibration. This type of set is, however, applied only to saws of $\frac{1}{2}$-in. width.

The second is termed the heavy set, i.e. 0·042-in. width of teeth (approximately 0·007 in. set on each side). This is, of course, the most usual set. As it cuts a wider kerf, it gives more play to the saw back and so enables smaller radii to be cut.

Narrow bandsaws are usually supplied in coils of 50 and 100 ft. in length. No hard-and-fast rules can be laid down for saw life, but a typical output before the scrap stage is reached is 100 linear ft. of 1-in. thick cold-rolled steel sawn by a bandsaw $\frac{1}{2}$ in. wide by 10 ft. in length. The same saw will cut 50 linear ft. of oil-hardening tool steel.

Saws are cut in six, eight, ten, twelve, fourteen, eighteen, twenty-four, or thirty-two teeth per inch. The speed of sawing is shown in the appended table. Contour sawing is sometimes used in place of nibbling.

Circular-saw Sizes.—The following may be taken as a guide when sawing tubing. For brass and copper tubing use a high-speed steel slitting saw. For tubing up to 1-in. diameter with a wall thickness up to 0·050 in., the saw should be 10-in. diameter by $\frac{1}{16}$ in. thick, with 180–200 teeth and a tooth hook angle of 10–15 degrees. The saw should run at a peripheral speed of 5–6000 ft. per min., with a feed of 50–200 ft. per min., according to the type of alloy. For tubing up to 1-in. diameter with a wall thickness of 0·05–0·25 in., the saw should be 10-in. diameter by $\frac{3}{32}$ in. thick, with 180–200 teeth and a hook angle of 10–15 degrees. Peripheral speed 406,000 ft. per min., according to the type of alloy, with a feed of 25–100 ft. per min. For tubing from 1–3-in. diameter with wall up to 0·1 in., the saw should be 12-in. diameter by $\frac{5}{64}$ in. or $\frac{1}{8}$ in. thick, according to the type of alloy, with 90–120 teeth, and a hook angle of 5–15 degrees. Peripheral speed 3–5000 ft. per min., with a feed 25–100 ft. per min. For tubing 1–3 in. diameter with wall 0·1–0·25 in., the saw should be 12–16-in. diameter, according to the type of alloy, by $\frac{3}{32}$ in. or $\frac{3}{16}$ in. thick, with 110–120 teeth and a hook angle of 5–15 degrees. Peripheral speed 3–5000 ft. per min. Feed 25–100 ft. per min. For steel tubing, saw 5-in. diameter by $\frac{1}{16}$ in. thick with a hole to suit the arbor.

Handsaws.—Blades for handsaws are generally made in 8-in., 10-in., and 12-in. lengths, although special lengths are obtainable to order. They may be obtained with hardened teeth and soft backs, or hardened throughout. There are also double-sided blades with soft centres. For mild steel, blades should have 18 teeth to the inch. For hard steel and brass, 32 to the inch, and for tubing, sheet, etc., 32 to the inch. The usual width of hacksaw blades is $\frac{1}{2}$ in. and the thickness 0·025 in. Some makers supply a variety of thicknesses.

JIGS, TOOLS, AND FIXTURES

A "jig" is that into which the component to be machined is located and which has the necessary bushes which locate the tool or tools in the correct relationship with the locating points of the component.

A "fixture" locates the component similarly to a jig, but it does not have any bushes, etc., in which the tools locate. The main purpose of a fixture is to locate the component which has to be machined in the correct relationship to the tools or to locate the component so that it is possible to machine it more easily than it would be without any fixture.

Below are listed a few of the troubles which are fairly common occurrences in most firms working on a large variety of components.

Locating Spigots.—The trouble is caused because not enough "clearance" has been allowed below the "bottom limit" in the bore size of components, which makes it impossible for the operator to fit the component into the correct position. The same thing often happens to recesses in fixtures when not enough "clearance" has been allowed over the "top limit" of the component. Where possible, a chamfer or radius should be machined on the spigot or recess in the fixture to help in loading the components.

Casting Foul Sides of Fixtures.—This often happens where the designer has not allowed enough clearance to allow for inaccuracies in the castings, which often occur.

Insufficient Swarf Clearance.—The designer must remember that in some types of fixture swarf clearance must be made, and where a passage or gap is made for the swarf, then the mouth of the clearance space and the space itself must be large enough to ensure that it does not get choked up during each operation.

Clamping Methods.—The type of clamp or clamps used is the part of a fixture which decides whether a fixture can be worked efficiently in loading and unloading.

A clamp must be (1) easy to handle; (2) bolts and the clamps themselves must be quick to operate; (3) clamps must be strong enough and must hold the component rigid; (4) clamps must not strain component.

Size of Bolt	*A*	*B*	*C*	*D Rad.*
in. dia.	*in.*	*in.*	*in.*	*in.*
1	$1\frac{3}{32}$	$2\frac{1}{8}$	$\frac{9}{16}$	1 [illegible]
$\frac{7}{8}$	$\frac{31}{32}$	$1\frac{7}{8}$	$\frac{1}{2}$	1 [illegible]
$\frac{3}{4}$	$\frac{13}{16}$	$1\frac{3}{4}$	$\frac{15}{32}$	1 [illegible]
$\frac{5}{8}$	$\frac{11}{16}$	$1\frac{1}{2}$	$\frac{3}{8}$	1
$\frac{1}{2}$	$\frac{9}{16}$	$1\frac{3}{16}$	$\frac{5}{16}$	$\frac{13}{16}$
[illegible]	$\frac{13}{32}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{5}{8}$
[illegible]	$\frac{9}{32}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{7}{16}$

A brief description is given of several types from which a choice can be made for most fixtures. A popular clamp is shown in Fig. 1. With this type it is advisable that the end of the clamp which makes contact with the component should be straight across and should be rounded off in one direction, as shown. The heel of a clamp is better rounded off in two directions so that it has point location, which ensures that end (A) beds down securely on component. Machining a handling slot down each side assists the operator in loading and unloading. The elongated slot for the stud is to allow for its being drawn back to clear the component. When the component varies slightly in thickness the ordinary nut and washer are not always seating square on the top of the clamp, so to overcome this difficulty a spherical nut or spherical washer is fitted. A spring under the

clamp is generally a great advantage, as it ensures that the clamp does not fall down and make it difficult for the operator in loading and unloading the fixture.

With clamps of this type x should be at least equal to y and where possible should be greater than y. Another point to consider on all clamps is whether the heel, clamping pad, and spherical seating (when used) should be hardened. This depends on the number of components to be machined and whether a hardened clamping pad (A) would damage the components.

Firms which are frequently using spherical nuts and washers have their own standard sheets of sizes. The table on **p. 1141** gives some washer sizes which have been proved successful in actual practice. For spherical nuts the radius (D) is the same (see Fig. 2).

Clamp Heels.—When a fixture has to take components of different sizes the heel of the clamp cannot be made like that shown in Fig. 1, but has to be adjustable (Fig. 3 (*a*)). A disadvantage with the type of heel shown in Fig. 1 is that it has to be made from a forging or machined out of the solid. A standard setscrew and locknut can be used with the adjustable type shown in Fig. 3 (*a*), and a radius must be turned on the head of the setscrew. With the fixed type, shown in Fig. 3 (*b*), a spherical-ended pin is driven into the body of the fixture and reduced at the upper end to keep the clamp in position.

Finally, with the solid type, Fig. 3 (*c*), a lug cast on the body of the fixture will make an ideal heel, and it is sometimes better to cast a wall each side to locate the clamp.

Clamping for Sleeves and Rings Located on Spigots.—Two ways of holding cylindrical components on spigots are shown in Fig. 4. Fig. 4 (*a*) is a slotted washer which clamps direct on to the component, and saves taking the nut off the stud each time, whilst Fig. 4 (*b*) shows a clamping plate and slotted washer. The hole (A) in the clamp plate must be large enough for the nut (B) to pass through after the slotted washer has been withdrawn.

There is one disadvantage with the type shown in Fig. 4 (*b*), which is that owing to the slip washer being a loose piece it is liable to get lost. It can be chained on to the clamp plate, but this is not always practicable. To overcome this difficulty the "C" washer shown in Fig. 5 (*a*) can be used. The sizes given in the table below for the "C" washer (Fig. 5 (*a*)) have been found to be successful in practice.

Size of Bolt	*A*	*B*	*C Rad.*	*D*
in. dia.	*in.*	*in.*	*in.*	*in.*
$\frac{5}{16}$	$1\frac{9}{16}$	$\frac{1}{4}$	$\frac{9}{16}$	$\frac{11}{32}$
$\frac{3}{8}$	$1\frac{3}{4}$	$\frac{1}{4}$	$\frac{21}{32}$	$\frac{13}{32}$
$\frac{1}{2}$	$2\frac{1}{8}$	$\frac{5}{16}$	$\frac{13}{16}$	$\frac{17}{32}$
$\frac{5}{8}$	$2\frac{1}{4}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{21}{32}$
$\frac{3}{4}$	$2\frac{3}{8}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{13}{16}$

The "C" washer shown in Fig. 5 (*b*) can be used where it is possible to allow a greater distance between centre of the swivel screw and centre of bolt than that allowed with (*a*), Fig. 5.

Latch Clamp.—Another type of clamping device is the latch type shown in Fig. 6. This type is used when a component has to be withdrawn from the top of the fixture. A latch clamp having a vee (*f*) as shown can often be used for clamping and locating the component. The action of the latch is fairly obvious.

A silver-steel pin (*a*) should be a "run fit" in the holes, in both the latch and the side holes in the fixture body. The pin should be held in position by a grub screw; fixing it this way ensures that standard reamers can be used for the holes and that the pin has not to be ground down to give a "run fit" in the latch and a "drive fit" each side. Pins (*b*) and (*d*) should be fitted the same way as (*a*). The end of latch (C) should be radiused as shown so that the nut on the eye bolt can swing clear more quickly. The vee (*f*) swivels at (*d*), which ensures that the vee is clamping evenly on component.

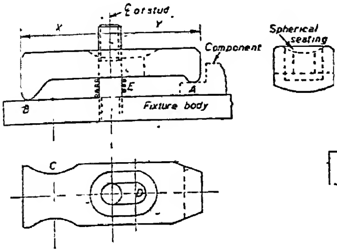
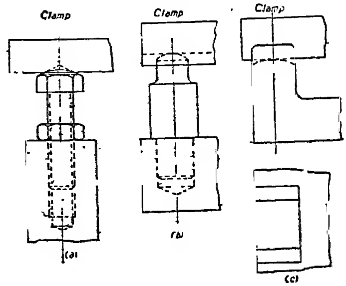


Fig. 1.—A popular type of clamp.

Fig. 3 (*Below*).—When a fixture is to take components of different sizes, the heel of the clamp must be adjustable as shown at (*a*). A fixed type is shown at (*b*) and a solid type at (*c*).



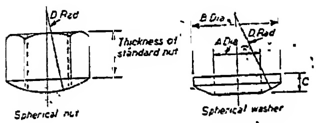
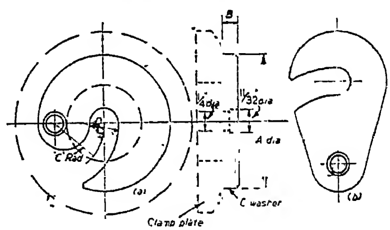


Fig. 2.—Details of a spherical nut and washer.

Fig. 5 (*Below*).—Avoiding loss of the slip washer when it is a loose piece.



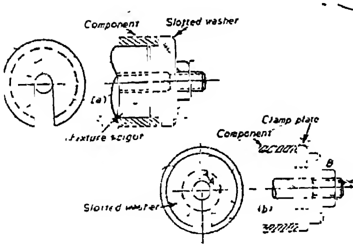
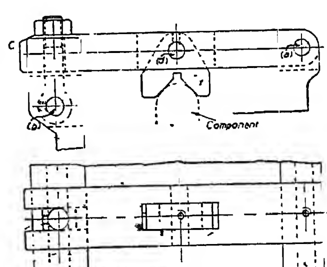


Fig. 4.—Two methods of holding cylindrical components on spigots.

Fig. 6 (*Below*).—The latch type of clamping device.



In modern establishments tool designs are produced by a tool-drawing office and the various stages of the work executed by specialists, whereas in smaller ones the matter of design may be left to the skilled toolmaker entrusted with the work. Where such a practice prevails, the toolmaker must be capable of carrying the work right through from start to finish, and is usually required to do this.

Tool Design.—The question of tool design is governed by the number of pieces to be handled by the device under consideration.

Jigs.—A jig is a device provided with one or more guides (for cutting tools) in which the work is located and held in correct disposition in relationship to the guides. Jigs are commonly associated with drilling and like operations, and may consist in some cases, where the holes to be drilled are in one plane, of little else than a flat plate in which are housed the tool guides. This arrangement presents the jig in its simplest form. Other circumstances, such as where the holes lie in more than one plane, or where the points of location are inconveniently situated, dictate the conformation of the jig, which in many cases consists of a box-like structure.

Fixtures.—A fixture is a work-holding device, and is intended to provide a means of mounting work on a machine for the purpose of performing an operation in correct relationship to a previously machined surface, or surfaces, without the necessity of setting-up the work. In order that the fixture itself may be located correctly on the working surface or table of the machine tool with a minimum of trouble; keys are provided in the base to engage with a table slot, or where the fixture is intended for use on a lathe or similar tool, a short spigot is provided on the back to correspond with a register turned in the faceplate. Apart from machining, fixtures are also widely used in connection with assembling operations. Examples of a jig and fixture, both of simple design, are illustrated in Figs. 7 and 8.

For a jig to prove successful in use, the following points must have been studied in the course of design: (1) Correct choice of locating points. (2) Making adequate provision for removing swarf from locating surfaces easily. (3) The means of holding or clamping the part must be such that it will not cause distortion. (4) Making provision to support the part where necessary to guard against cutting pressure causing distortion. (5) Ease of loading and removing the work after completing the operation. (6) Arranging the tool guides as near to the work as possible and making them of ample length. (7) The elimination as far as possible of the likelihood of swarf preventing the jig from standing level on the machine table by raising the base on feet. (8) Arranging the feet in such a manner that the cutting pressure cannot cause the jig to tilt, and lastly that the jig is easy to keep clean during use. The same points arise where a fixture is concerned, with the exception of those stressed in numbers (6), (7), and (8).

The locating points chosen, i.e. the surfaces of the work which abut against or rest on stops placed in the jig to determine its position relative to the tool guides, should be those which have to be maintained at a constant dimension and from which other main dimensions depend. It will be seen, by referring to Figs. 7 and 8, that the jig is located in the centre hole of the work. Where the jig is located on the outside diameter, the drilled holes, while right in themselves as regards spacing, could lie on a pitch circle eccentric to the bore by as much as the tolerance allowable on the comparatively unimportant external diameter. This, of course, is an elementary example, but it plainly shows the trouble that is likely to ensue from incorrect location in a more complicated piece of work or where perhaps more than one jigging is necessary.

It is obvious that if the stops provided in the jig as location points are not kept free from metallic particles, the work produced cannot be uniform. This liability is best frustrated by having the surfaces of the means of location visible to the operator and by the avoidance of sharp corners in which swarf may collect.

Clamping arrangements which cause distortion may permanently deform the work or allow the work to resume its normal shape upon removal from the jig, when an inaccuracy in the drilling becomes apparent.

The lack of proper provision, where necessary, against the work springing or distorting during machining will produce similar results. Where the design of a jig is such that the loading operation is made difficult, the loss of machining

time may seriously affect production. While the loading may be an easy matter, the removal of the work can be rendered difficult by the failure to provide clearance for machining burrs. Such a happening will necessarily slow up the work, and most likely cause damage to the work by having to apply force to assist in its removal.

Unless the tool is guided almost to the point where it makes contact with the work, inaccuracies are liable to creep in on account of " drill run." A guide that is too short in comparison with its internal diameter can also produce similar results. Jigs that are made to stand on a flat base can cause constant trouble by reason of drilling or metal chips becoming embedded therein, thus leading to inaccuracy and tool breakage. An improper arrangement of the feet provided to counteract this objection will have the same effect.

The nature of the service that tool guides have to perform demands that they be made from material not easily damaged by the cutting edges which come into contact with them. These guides are made in the form of bushes, cast steel being employed for making the smaller sizes. Larger ones are usually made from case-hardening mild steel. After suitable treatment the bores are finished by lapping or grinding to suit the " land " sizes of the cutting tools for which they are intended. The external diameters are then ground to size to ensure that the bushes are truly concentric.

Use of Bushes.—Various types of bushes are used according to the nature of the work to be done. In certain instances the use of a headed bush is precluded. In such cases a flush type of bush is employed. Where a hole requires reaming after drilling a slip bush is used. Here the hole in which the bush or bushes fit is provided with a liner to guard against the jig body becoming worn by constant insertion and removal of the slip bushes. The question of whether a separate bush is required for guiding the reamer will depend upon the positional accuracy demanded.

A slip bush is also necessary where a counter-boring or spot-facing operation follows the drilling. Where this occurs the internal diameter of the liner requires to be such that it will guide the body of a pilotless cutter or, if otherwise, to clear it. Provision has to be made to prevent the slip bushes from lifting out or turning in the liner when in use. This is accomplished in a variety of ways, but most usually by the provision of a bayonet-catch arrangement.

While a knurled head will afford a grip sufficient to manipulate a small or medium-sized slip bush, larger ones are often operated by means of a tommy bar. This bar may be a loose one or fixed into the head of the bush. Where the latter arrangement prevails it can be made to provide the means of retention also, as will be seen by reference to Fig. 9.

In certain forms of jigs the use of projecting catches as a means of securing slip bushes is precluded on account of the necessity for preserving unbroken flat surfaces with the bushes removed. In such instances it is usual to accomplish the locking of the bush by means of a pin inserted under the head, and to incorporate the catch in the liner, as in the manner illustrated in Fig. 10.

Bearing in mind the necessity for having the guiding surface for the cutting tool situated as close to the work as possible, it may be that one or more holes are located at the bottom of a cavity. Where this occurs and the depth of the cavity is suitable for a standard drill, the bush is made to accommodate an extension shank, as shown in Fig. 11. Even where a standard drill can be used, the mouth of the bush should be relieved by counterboring in all cases where the design dictates that its length needs to be above the normal.

Screwed bushes are sometimes used to serve the dual purpose of guiding the cutting tool and securing, or assisting to secure, the work in the jig. This arrangement is not to be recommended, but where it is employed the thread must not be relied upon to locate the bush. A plain portion in the liner or insert for this purpose permits the thread being made an easy fit. Such a bush is shown in Fig. 12. Here the end of the bush is coned out, when it may be used to locate and hold a cylindrical boss on the work to be drilled. Where a bush of this description is employed, the opposing surface of the jig would be flat if the boss be on one side of the work. It may be, however, that the hole to be drilled is to pass through the end of a drop-forged lever having a boss on either side, in which case the screwed bush can be opposed by a fixed female coned bush to

locate the underbossed portion. By the omission of the coned end, it will be apparent that the bush can also be used for holding flat work.

Methods of Holding Jigs.—The manner in which a jig is held or secured to the machine table while the operation is being performed will depend upon the size of the job, or, rather, that of the drill or drills necessary to carry out the work and the type of machine available for the purpose. Thus, for a job that requires a series of small holes drilled by a sensitive drill, the jig can be provided with a handle for hand steadying.

With a similar machine and where the job is one that calls for one small hole only in each piece, the risk of drill breakage can be greatly minimised by securing the jig in the correct drilling position on the machine table by clamping. Reverting to the first example, the jig can be permanently fixed to the machine table during use where an adjustable multi-spindle machine or multi-spindle drill head is available for the purpose.

Work of a heavier nature, which has to be carried out on a multi-spindle machine to overcome the necessity for making three or four tool changes during the performance of a cycle of operations, necessitates the moving of the jig from spindle to spindle on a common table. Here it is sometimes possible to arrange for the jig to slide between long, parallel strips bolted to the machine table.

Jigs intended for use on pillar or radial drilling machines must be provided with bases to bolt on, or other provision made to clamp them down to the machine table. Where the drilling has to be carried out in more than one plane, it is often advisable to mount the jig proper by means of trunnions in a substantial frame which is bolted to the machine table. The various bushed surfaces of the jig are then brought into correct relation to the drill spindle by means of indexing mechanism.

Special-purpose or adjustable multi-spindle machines for drilling holes in different planes simultaneously would naturally require to have the drilling jig rigidly fixed in position.

Types of Drilling Jigs.—Drilling jigs may be divided into three main types, namely, plate jigs, built-up jigs, and cast box jigs. Any jig is, of course, in reality a built-up jig, as seldom does it consist of only one piece ; but the terms mentioned refer mainly to the form which the jig body assumes.

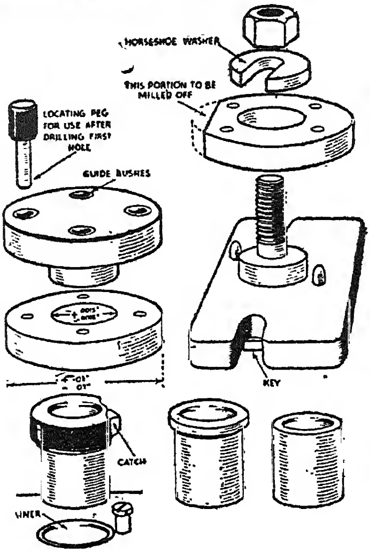
In some instances a flat plate of metal suitably bushed and provided with some form of clamping device and suitable location points will provide the necessary jig. Other jobs demand that the jig be built up from steel or cast iron or a combination of both materials. While jigs may be built up from flat steel by a system of screwing and dowelling into a box-like formation, this practice is not one to be recommended for those of large proportions and where the metal forming the bodywork has to be left in a soft condition, as constant use will most certainly render such jigs inaccurate.

The more satisfactory method for such jigs is to utilise a casting made from a pattern in which are incorporated the necessary bosses, projections, and stiffening webs as may be necessary to provide rigidity.

Methods of Construction.—A plate jig can consist of a flat bright steel or machined cast-iron plate, into which hardened steel feet are screwed in the manner shown in Fig. 13. The height of these feet requires to be such that they will raise the clamping arrangement used clear of the machine table.

Where this method of construction is used, the means of location is usually secured by pins or suitable contoured plates screwed to the underside of the plate. A properly made casting for a similar jig can have stepped surfaces and abutments for location points cast integral, when there will be less likelihood of pieces working loose and causing variations in drilling.

One form of built-up jig which provides a rigid construction is that illustrated in Fig. 14. Here the top and bottom or bush-carrying plates are separated and secured by four or more pillars. At the ends, these pillars are shouldered down to pass through holes drilled in the corners of the plates. Hardened steel cap-nuts screw on to the shouldered ends to secure the pillars to the plate and form feet. Needless to say, for accurate results the distances between the shoulders on all pillars need to be exactly maintained, as does the over-all length of the nuts. While of simple construction this form of jig will, with certain modifications, serve as a basis of "jigging" many jobs.



Figs. 7 and 8.—A simple type of jig and fixture.

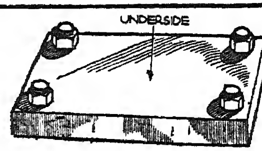


Fig. 13.—Details of the plate jig.

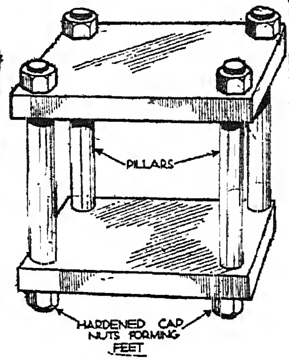


Fig. 14.—A built-up jig.

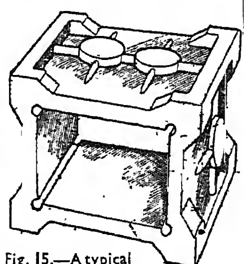


Fig. 15.—A typical casting for an open-sided box jig.

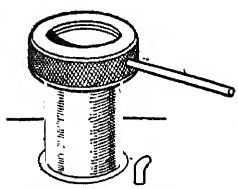


Fig. 9.—How a tommy pin may be used to form a means of retention for slip bushes.

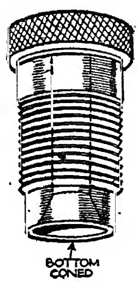


Fig. 12.

Fig. 12.—The end of the bush coned out to enable it to be used to locate and hold a cylindrical boss on the work to be drilled.

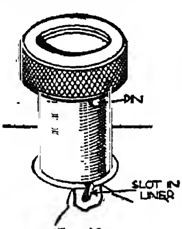


Fig. 10.

Fig. 10.—Another method of achieving the same object as shown in Fig. 9.

Fig. 11.—A bush made to accommodate an extension shank.

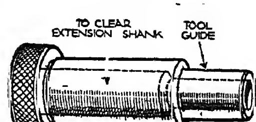


Fig. 11.

This is but one of the many examples of built-up construction, but it is one that is typical of the class in general. Wherever the building-up process is employed, reliance should never be placed entirely on the use of slotted-head screws. Bolts afford a better medium for securely holding the parts together, but the disadvantage of such a method is that bulky heads may cause interference. Hollow-head cap screws provide a neat and effective alternative. The heads of these screws are small in comparison to those of bolts, and require to be seated into counterbores in the same manner as cheese-head screws, but unlike which they can really be tightened. This being so, reliance should never be placed on the screws alone for maintaining the parts of the jig in position, and, therefore, all important parts at least should be additionally secured by dowelling.

Jigs of the cast box type require careful designing with a view to providing sufficient strength without unnecessary addition to the total weight, and also as to the ease of machinability of the jig interior.

Actual examples of cast box-jig construction will be given later. One important point relating to jig feet in general is to see that they are so disposed and of sufficient size not to drop into or foul the table slots or holes in the machine table on which the jig is to be used.

Jig Bodies.—The bodies of box jigs are mainly made from iron castings. It is necessary for this form of construction to have a pattern prepared from which to produce the casting. A typical casting for an open-sided box jig is illustrated in Fig. 15. This represents but one form of this class of jig, and for its completion it needs surface machining and boring correctly to receive the guiding bushes, and must be provided with suitable work-holding arrangements. Other forms of work may need a complete box shape, when the lid of the box may be hinged to permit the loading and unloading of the jig. Large jigs of this description may require to be built up from cast sections, or the same principle may have to be adopted where the internal machining of the jig would otherwise be rendered difficult or impossible.

The jig casting requires to be designed in accordance with the shape of the job to be handled, when bosses for bushes, pads for supporting the work, and seatings for locating pieces can be correctly disposed on the pattern for incorporation in the casting.

It is intended at a later stage to give suggestions for "jigging" several concrete examples of work, with a view to covering briefly the problems likely to be encountered. This particular type of jig can then be more fully dealt with in its completed form.

Methods of Clamping.—While it is true that certain work may be held in a jig without being clamped in the ordinary sense—as, for instance, where a large, bored cross-hole lying parallel with a machined surface requiring to be drilled can be held in position by means of a cross-pin or mandrel passing through the jig and the work, in the majority of cases the holding has to be accomplished by some form of clamp or clamps.

The point of application of each clamp needs to be considered from the viewpoint of its liability to cause distortion of the work upon being tightened, and at the same time the clamping arrangement must provide adequate support where the machining is being performed against it.

Generally speaking, the operation of any jig is retarded where it is necessary to remove nuts from studs before the jig can be loaded and unloaded. In fact, it is better wherever possible to avoid loose pieces of any description. This is not, however, always possible without the addition of unnecessary complications. A particularly simple form of clamping that is effective for work having a central hole that has been machined at a previous operation is that shown in Fig. 16. Here a central stud—tapped into the bushed surface of the jig—is provided with a substantial slotted washer, of sufficiently large diameter to encompass the hole in the work, which is tightened down by means of a flanged nut. It will be apparent that by slackening the nut slightly the washer may be slid out and the work removed over the stud without taking the nut off the stud.

Where circumstances permit, the nut shown may be modified to dispense with the necessity for employing a separate spanner or key for tightening and loosing.

This form of clamping is satisfactory for work of substantial proportions, or where the holes to be drilled are disposed reasonably close to the point of support,

otherwise for similar work of a lighter nature the clamping arrangement illustrated in Fig. 18 may be employed. This consists of a spider, having legs of suitable length to engage the surface of the work, the central hole being large enough to clear the clamping nut, as in Fig. 17. Where the surface against which the legs bear is irregular in relation to the machined surface of the work opposing the locating face of the jig—as, for instance, a rough-cast or stamped surface—the ends of the legs should be domed and the surface about the centre hole in the spider machined concave. The under surface of the washer will then need to be machined convex to correspond, thus forming a compensating clamp which will take care of any unevenness in the surface of the work.

Plate Clamps.—A simple form of plate clamp is seen in Fig. 19. This may consist of a plain slotted plate as shown, when the heel piece of suitable height to correspond with the thickness of the work is attached to the jig. The clamping stud should be arranged in such a position as to permit the front of the clamp being slid clear of the work without entirely removing it from the stud.

Where this type of clamp is used, the front of the clamp is retained at its normal height when the work is removed by means of a light compression spring passed over the stud. Where it becomes necessary to remove the clamp entirely to facilitate loading and unloading, the slot may be run out to the front of the clamp or the front end of the slot may terminate in a hole large enough in diameter to clear the clamping nut. A certain degree of compensation for taking care of variations in thickness of the work may be obtained by providing a lip on the underside of the clamp bearing against the work. Where this is done the surface clamping nut requires to be convexed and the top of the clamp machined concave to suit the appropriate position. The surface of the heel will also need to be made convex, these precautions being necessary to avoid bending the stud when tightening.

Swinging Clamps.—An alternative form is necessary in certain instances. Use can then be made of a swing type of clamp, such as that illustrated in Fig. 20. The clamp as shown is mounted on pillars, but the pivoting stud and anchor could be incorporated on the edges of a box jig. The stud is made with two diameters so that the nut and washer may be tightened down, leaving the plate or strap free to swing on the larger diameter. The anchor pillar is necked in to receive the slotted plate freely, and the centre of the slot is cut on a radius equal to that of the pillar centres. The distance between the pillars is made to suit requirements, and one or more clamping screws may be provided.

A similar form of clamp for use under different conditions is seen in Fig. 21. This plate swings about a pin set in the bossed end of the plate. At the opposite end the plate shuts down on to the edge of the jig. With such a clamp it would be necessary to remove the knurled nut before the plate could be raised if a fixed stud were employed. To obviate the necessity it is usual to fit a swing stud. Here the stud is bossed at its lower end and drilled to swing about a pin set in a fork or slot cut in the jig body. With this type of clamp it is possible to dispense with the stud and nut and fit a refinement in the shape of a quick-acting latch device. This naturally involves more work in the making, but where the job warrants adopting this alternative arrangement the trouble will be amply repaid on the saving in operating time.

Sliding Bars.—A similar effect to that just described may be obtained in a simple manner with a loose square or rectangular bar sliding in suitably shaped holes cut in both sides of the jig body. To render the removal of the clamping screws unnecessary, one of the holes is slotted through to permit the screws to pass.

Owing to the severe work usually imposed on the clamping details of jigs during their use, all studs should be made from high-tensile steel, and all plates, nuts, and the ends of clamping screws hardened.

Pneumatically-operated Clamps.—Where an airline is available it is often possible to incorporate pneumatically operated clamping devices. For larger classes of jigs it is possible to obtain air-operated units made for this express purpose. Needless to say, where it is possible to adapt such power for this purpose the operator is relieved of much tedious work, and its benefit is greatly reflected in output on work of a heavy nature. Apart from this, the pressure exerted on the work to hold it in position is always constant.

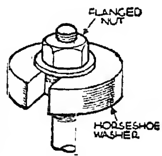


Fig. 16.—A simple form of clamping.

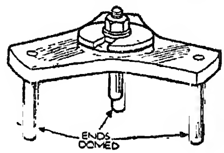


Fig. 18.—This clamping arrangement is of the spider type.

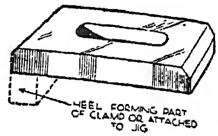


Fig. 19.—A simple form of plate clamp.

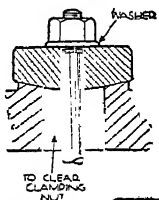
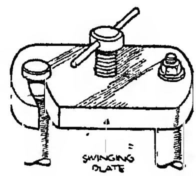


Fig. 17 (*Left*).—The central hole should be large enough to clear the clamping nut.

Fig. 20 (*Right*).—A swinging type of clamp.



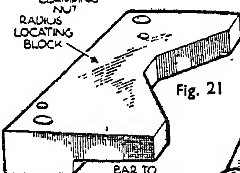


Fig. 21

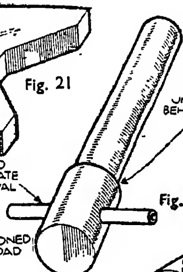


Fig. 26

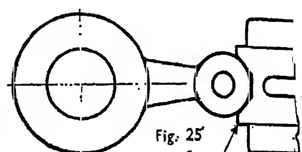


Fig. 25

ADJUSTABLE VEE-BLOCK TO CENTRALISE SMALL BOSS

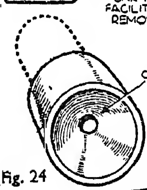


Fig. 24

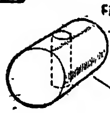


Fig. 27

Fig. 23

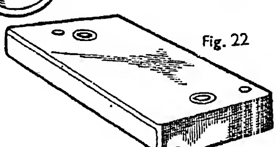


Fig. 22

UNDERCUT FOR SWARF CLEARANCE

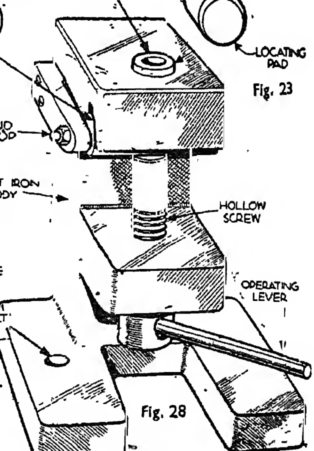


Fig. 28

Fig. 21.—A vee block for locating work from a radiused end.
Fig. 22.—A block for the location of plane surfaces.
Fig. 23.—Use of pads.
Fig. 24.—A female coned pad.
Fig. 25.—A bossed lever.
Fig. 26.—A hardened and ground locating pin.
Fig. 27.—Typical jigged component.
Fig. 28.—Details of the jig.

The work is positioned in the jig in such a manner that the holes, when machined through the guide bushes, are correctly located in every respect. In order that this object may be achieved, it is necessary to provide in the jig stops against which previously machined surfaces may abut or fit. In many cases the choice of locating surfaces is automatic, and where two or more separate jigs are required for one job the original datum faces are maintained throughout the operation.

It will be realised that it is not possible to deal exhaustively with this particular subject as so much will depend upon the actual shape of the part to be handled, but a few methods used singly or in combination will briefly be described. These should cover the classes of work most commonly encountered.

Locating with Vee Blocks.—Vee blocks provide the means of locating work from a radiused end. Such a block is seen in Fig. 15. The depth of the block is made to suit the job, but provision should be made for swarf clearance in the manner shown.

The block shown in Fig. 16 is for the location of plane surfaces. Here again the face is cut away at the bottom to prevent swarf building up in the corner. Where it is not convenient to use a block form of location, one or more pads, as shown in Fig. 17, may be employed. These may have plain ground shanks for pressing into a drilled or reamed hole, or screwed to fit into a tapped hole. In either case the underside of the head is undercut to permit grinding and the face of the head ground to give a predetermined thickness after hardening.

Illustrated in Fig. 18 is a female coned pad. This is suitable for the location of spherical-ended work. Where the work is slotted a bar is arranged in front of the pad, but clear of it and clear of the bottom of the slot.

Here again such a pad may have a parallel-ground shank pressed into a reamed hole or a thread provided in addition and the pad secured in position with a nut.

Bossed Levers.—Fig. 19 represents a bossed lever. This is located from the large bored hole by means of a plug. The smaller boss is positioned centrally by a sliding vee block working in guides and backed up by a cam or an adjusting screw. As will be seen in this arrangement, the location so far as the centre distance of the holes is concerned is governed by a plug fitting into the bored hole, the vee block positioning the smaller boss in a lateral direction. A great deal of machined work can be located from bored holes or registers for drilling.

In certain circumstances, such as where a long bored hole passes through the work from a machined face, the opposing sides of the jig body are bored to receive a hardened and ground locating pin such as that shown in Fig. 20. This pin is chamfered at the front end to assist in leading it into the work. The head may be knurled or provided with a cross pin, as illustrated, to facilitate its removal.

When locating from a male or female register, the jig body is usually appropriately bored or provided with machined projections to suit the work. The question of swarf clearance has to be studied carefully, and for this reason the mouth of the hole or recess in the jig used as a register requires to be chamfered, or where a male plug or insert provides the location the base of the plug should be undercut to avoid loose metal chips, likely to prevent a proper seating, from being trapped in a corner.

Seldom is it necessary to jig parts entirely from surfaces as cast or forged. While it is true that machine-moulded castings and drop-forgings generally are produced approximately uniform in size, some form of adjustment or compensation should be allowed for in the locating points of the jig in which such a part is to be handled. Flat surfaces should be supported where dimensions depend from such at three points on raised pads.

So far, the parts comprising an average jig have been dealt with briefly so as to impart a general idea of requirements covering different classes of work, but it will already be realised that many of the details, such as bushes, clamps, latches, studs, and pins, can be standardised.

In jig designing each problem presents its own difficulties, but there are recurrences of familiar types of work, and where a scheme has proved satisfactory on a similar job it may be readopted with perhaps small improvements or modifications.

Drilled Work.—A common type of drilling job is that shown in Fig. 21. The requirements are that a drilled hole passes through the centre of the work in both directions square with the axis. The simple jig illustrated in Fig. 22 is one that

will produce the results desired and is also capable of rapid manipulation. A casting forms the jig body, which is machined on the top and bottom faces. The inverted 90-degrees vee, with the root terminating in a shallow slot, at the top of the jig, is machined parallel with the base. A hole for the drill bush is bored central with the vee and a hole drilled and tapped in the centre lug in line with it to receive the pressure screw.

Securing the Jig to the Table.—Holes in the base lugs are drilled for the purpose of securing the jig to the drilling-machine table. The headed pressure screw is drilled through its centre to clear the size of drill used for the work. A short tommy bar secured into the head of the screw provides the means of securing and releasing the work-piece. A steel bracket screwed and dowelled to the side of the jig, and provided with an adjustable stop in the form of a screw tapped into the bracket and secured with a locking nut, affords the means of end location. Where more than one operation is necessary the jig is equipped with a liner and slip bushes, in which case, where the jig is to be operated on a two- or three-spindle machine, the base may be modified and a handle provided.

Where a series of jobs of a like nature to that shown in Fig. 21 is to be handled and differing slightly, perhaps, in diameter, length, and hole size, one jig may be utilised to deal with them all. When this is intended the end stop will require a range of adjustment sufficient to cover the longest and shortest of the parts. Slip bushes will be substituted for the fixed bush, and a series of tommy holes drilled and reamed in the bush head to permit the lever being moved to a convenient position when a smaller or larger diameter of work is being handled.

When the jig will see service over a long period, its durability will be enhanced if the vee-block portion is made from steel which is subsequently finished by hardening and grinding. This would be attached below the bushed portion with hollow-cap screws and dowels. It will be apparent also that this jig lends itself to a built-up form of construction from steel. Naturally this will be the course to adopt where the work is of small proportions, say below $\frac{3}{8}$ in. in diameter.

By a slight modification this design lends itself admirably to the drilling of pin holes; for the majority of split-pin holes in bolts or clevis pins the pressure screw would need to be at a point behind the bush. The form of end location shown could be dispensed with, as hole centres for this class of work given usually are from under the head. The edge of the vee block could be used as a locating face, or where length variation has to be coped with an adjustable stop, sliding through and clamped in a hole in the back of the jig, can be provided. (See Fig. 23.)

Where two holes are required side by side, one solid pressure screw between the holes will form the method of clamping.

The work-piece shown in Fig. 24 is drilled in the base and through one side. The side hole is counterbored after drilling, while the work is still in the jig. Actually the example can represent a casting or drop forging, and the only machining performed on the part prior to drilling is that on the bottom surface. This consists of milling the base and the slot extending from end to end of the part. In such a case as this it would be correct to presume that the base would be machined to a dimension taken from the top of the boss and, therefore, as the hole in the boss would need to be approximately central, the part would be positioned endwise in the jig by means of a clamp engaging it.

A Jig for Handling the Part.—A suggested method of handling the part illustrated in Fig. 24 is shown in Fig. 25. As will be seen, the "built-up" method of construction is employed. The side plates are of cast iron, machined on both sides, and are slightly relieved in the centre bottom to leave feet at the ends. At the top (as drawn), the plates are cut away in a similar manner, but to a greater extent, to permit easy access to the clamping screw in the swinging clamp member. The bottom member is of steel and has a machined tongue to register the slot in the base of the work-piece. It is intended that the tongue should clear the bottom of the slot by a slight amount. Therefore, the sides of the tongue should be undercut at their junction with the base in order to provide swarf clearance. This part carries the bushes for the blind holes shown dotted in Fig. 24, and should be subsequently hardened and finished by surface grinding. Needless to say, in any event the surfaces which abut on to the side plates require to be parallel.

The side plates are attached to the base member by means of studs passing

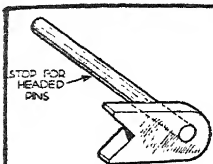


Fig. 23.—An adjustable stop.

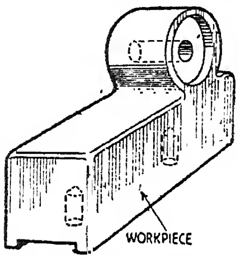


Fig. 24.—A work-piece drilled in the base and through one side.

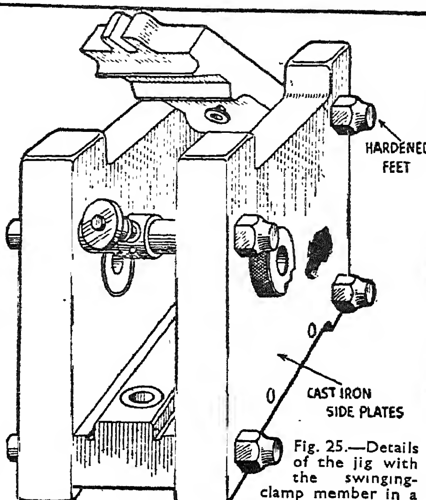


Fig. 25.—Details of the jig with the swinging-clamp member in a raised position.

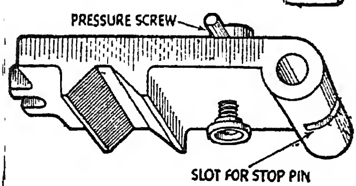


Fig. 26.—Another view of the swinging-clamp member.

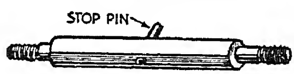


Fig. 27.—A stop pin fixed in the stud.

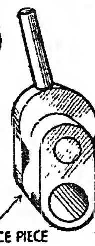


Fig. 29 (*Left*).—This device may be substituted for the swinging stud.

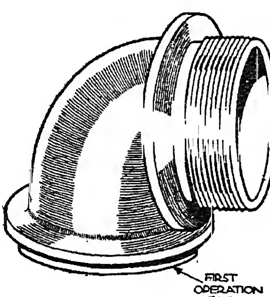


Fig. 30.

Fig. 28.—Showing the action of the clamping member.

Fig. 30.—A turning job which has been machined at a previous operation.

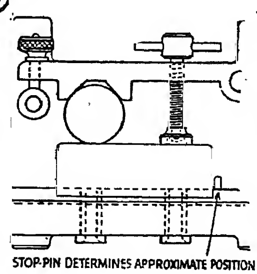


Fig. 28.

clear through the side plates and base member. Hardened jig feet in the form of blind nuts screwed on to the end of the studs secure the parts together. Additional security is provided by dowelling the parts on both sides.

At the top the jig side plates are separated by means of shouldered studs, as illustrated in Fig. 25. These studs are accurately machined over the shoulders to a dimension equal to that of the width of the base member. At their outer ends these studs are provided with feet similar to those at the bottom.

Swinging Clamp Member.—The swinging clamp member shown in a raised position in Fig. 25 is illustrated in Fig. 26. This may be machined from steel or made from a casting. In width this part requires to be slightly less than that of the base member in order that it will work freely between the side plates. The hole in the boss should be large enough to pass the largest diameter of the shouldered stud freely but without unnecessary slackness. The vee-block portion should be large enough to position the bossed portion of the work. A slot at the front end receives a swinging clamping screw. A slot at the back end of the clamp clears a pin fixed into the stud, as in Fig. 26, and its purpose is to prevent the clamping member from falling completely over when raised beyond the vertical. The pin is therefore positioned suitably to accomplish this object. The boss on the swinging stud is treated in the same manner as indicated in the illustration of the jig.

By reference to Fig. 28, the action of the clamping member is made clear. A stop pin in the base member roughly determines the position of the part in an endwise direction before the clamp comes into operation. The pin, however, should be so placed that the vee block will tend to draw the part away from it, otherwise the boss may not be centralised. After the clamp is tightened down on to the boss, the pressure screw is tightened to hold the back end of the casting down on its seating. This screw is provided with a swivelling pad to avoid marking the surface of the job. The side plates are bored to receive the bushes.

Should the fittings require to be "hardened," both holes should be fitted with liners to house the "slip bushes," otherwise only one side requires bushing and a clearance hole is provided in the opposite side plate to clear the counterboring cutter.

In order that the jig should lie properly on the feet, one set of feet needs to be surface ground, after securing, from one side plate, and the opposite set of feet ground while the jig is resting on the finished set. The top set of feet should also be surface finished after the jig is assembled.

Alternative Clamping Arrangement.—The device illustrated in Fig. 29 may be substituted for the swinging stud. It consists of a pair of short links separated by a tubular distance-piece. A simple cam has pins machined on either side to suit the smaller holes in the links. Where this method is adopted two short distance-pieces will be required to centralise the links on the stud. The slot at the front of the clamping plate will be replaced by a simple tongue. A short bar handle forms the means of operating the cam and is so positioned that when the clamp is secured it does not project above the jig feet.

Although the free end of the swinging clamp has no definite abutment against which to rest, it is not intended to take care of a wide range in variation of the depth from the boss to the base of the work. Therefore, even if a wider tolerance is permissible this dimension should be kept within $\frac{1}{32}$ in.

Surface Condition of Work.—Where the surface condition of the work about the boss is rough or uneven, it may be desirable to reduce the width of the vee block considerably in order to secure an average bearing. Should the boss be "barrel" shaped, as would be the case if the part were drop forged or hot pressed, the vee block will require clearing away in the centre to allow the vees so formed to bear on either side of the boss.

Where objection is taken to the method suggested for locking the clamping member, another arrangement may be substituted which dispenses with the necessity of tightening two screws. It consists of a spring-loaded vee block which is mounted on the plate in lieu of the fixed block. This will then allow the plate to shut against a latch such as that previously described. Where this course is adopted the position of the pressure screw is rearranged to distribute the load as evenly as possible between the holes in the base of the work.

For work needing a bottom location from a machined surface and approximate

end location for the centralisation of a boss, the only departure from the arrangement shown might be in the shape of the locating surface on the bottom member. An article having a double boss, that is, one like that illustrated in Fig. 24, at each end of the work, could be taken care of by a male vee block bearing between the inner flanks of the bosses and backed up by a pressure screw. For work where end location depends upon a previously machined face, a spring-loaded wedge attached to the hinged member can be utilised to press the surface of the work against a suitable end-locating pad in the jig.

The provision of suitably disposed projecting pads on the inner surfaces of the jig would permit the accommodation of work machined on the base and sides.

In passing, mention must be made of the fact that with the omission of the swinging-clamp arrangement and the provision of larger-diameter shouldered studs, drilled and tapped to pass pressure screws, the basis of a further design is provided for a great variety of work.

Fixtures.—The term "jig" is one that is often erroneously applied to a fixture. As stated earlier, a fixture is purely and simply a work-holding device not equipped with cutter guides. When intended for use on a machine-tool table or lathe face-plate, the base of the fixture is provided with a key, or keys, or a circular register, so that it can be accurately disposed on the machine without prior indication or measurement, therefore the fixture is merely bolted down each time it is used.

Fixtures are also employed for certain assembly operations, but in these circumstances the point just mentioned does not apply. Various types of work where fixtures may be profitably employed for the purpose of carrying out the operations indicated are illustrated in Figs. 30 to 35. That shown in Fig. 30 is a turning job which has been machined at a previous operation consisting of turning a male register and facing the flange at the bottom. The next operation calling for a fixture is that of turning and screwing the male thread, facing the flange, and undercutting the thread. The requirements are that the faces of the flanges shall lie at 90 degrees with each other and that the centre of the screwed nose shall be at a predetermined distance from the face of the bottom flange. In passing, mention is made of the fact that the same type of fixture which will be described would suffice if the angle between the faces is other than that mentioned. Where this is so, it follows that the portion of the fixture on which the work is mounted will lie at an acute angle in relation to the surface of the face-plate.

Milled Work.—Examples of simple milling operations are seen in Figs. 31 and 32. The first one would be milled with a gang of three cutters from the solid. The domed portion is "formed" in the turning operation. In the second example the parts are turned from square bar material, the slot is then milled at one operation and the radius at the end of the fork at another. Both of these examples would be held by the shank while the operations were being performed, and dealt with singly or in gangs of six or more at one pass of the cutters.

A broaching job is seen in Fig. 33. Here the requirements are that the splines are correctly positioned in relation to the hole in the small boss. In this instance the broaching would be done after the boring, facing, and drilling operations, the lever being positioned in relation to the broach teeth by means of a peg or pin passing through the hole in the smaller boss.

The assembly job illustrated in Fig. 34 consists of a flange attached to a tube by means of welding. Here the washer would be held in correct relationship with the ends of the tube and at the desired angle while being "tacked" at several points. The welding operation proper would be completed with the work removed from the fixture. This practice should not be taken as a general rule, for other types of work might require to be more rigidly held than is necessary in this instance. Where this occurs allowance has to be made in the clamping arrangements for expansion and subsequent contraction.

Assembly Fixtures.—Many light assembly jobs are greatly expedited by the employment of fixtures which are thus benefited even where close accuracy of the finished product is comparatively unimportant, but where close accuracy is demanded the use of a fixture for the purpose is practically a necessity.

Jobs of this nature may consist of the assembly of several pressings by means of rivets or spot welding. Smaller parts of the same nature might be joined together by eyelets or hollow rivets. Holes in parts thus joined would, for ease

of manipulation, be relatively large in relation to the diameter of the rivet or other means of fixing. Therefore, no reliance could be placed on the use of the rivets for the purpose of initially lining up the several components. An assembly job of a different type is shown in Fig. 35. Here the end brackets are attached to the shaft or tube by means of taper pins, and the bell-crank lever in the centre is free to rotate between a pair of collars similarly fixed. The essential features of this assembly are that the feet of the brackets should lie in one plane at a distance apart to correctly maintain the requisite centre distance between the fixing holes. Equally important is the disposition of the lever. Therefore, even if the assembly consists of placing the parts in position and taper reaming the holes, the brackets require to be fixed down in their correct positions and the lever also placed, before so doing, and driving home the pins. It is only by taking these precautions, even with so simple a job, that constant results will be obtainable.

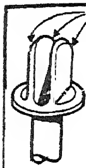
Handling Milled Work.—Reverting to the question of milling, the type of work shown in Fig. 31 presents no difficulty, as in this particular example the surfaces to be formed are lying in one plane. In the second example, however, the track of the machining is in two directions at right angles with each other. This means locating either from the slot, or from the square sides, to bring the work into correct relation with the concave cutter which forms the radius.

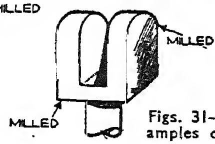
Where the milling operation consists of forming a square or other head of similar balanced section, such as may be formed by a pair of cutters, the point to be decided if gauge milling is to be adopted is whether the work shall be partially rotated mechanically between each pass of the cutters to bring about the desired result, or whether the purpose shall be achieved by relocating the parts after the completion of each cut. The partial rotation of each part, arranged in line simultaneously, will invariably mean the incorporation of gearing for the purpose. This point, coupled with the fact that collet-type work-holders would most likely then be necessary, leads to the conclusion that such a scheme will be one that will be costly to produce, but this will not prove a disadvantage where the outlay can be spread over a considerable quantity of parts.

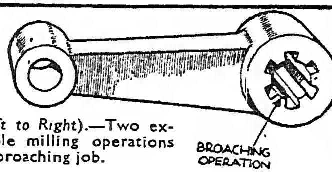
It might be that the fixture, with the provision of different-sized shank-adapters or collets, would prove suitable for the production of a range of similar parts. In this case the expense would be warranted. An alternative arrangement is to have a fixture that is capable of being indexed about a base and upon which the components are arranged in such a manner, on the rotatable portion, of course, as to permit their being machined in several lines at once by means of a gang of suitably spaced cutters. After one pass of the cutters the fixture is swung round to bring the unmachined portions in line with the cutters. This is a scheme which is much simpler to carry out, but one which, for obvious reasons, is unsuited for parts having long "shanked" portions below the milled surfaces. Items having tapped holes in them could naturally be handled in a similar manner by the provision of suitable mounting adapters.

Continuous Milling.—While dealing with this class of milled work mention should be made of the fact that there is a special horizontal type of milling machine that was developed for machining parts of a "special headed bolt" nature. The milling is carried out on the continuous principle, and the fixture employed is really a portion of the machine. Briefly, the work-pieces, held by the shanks, are passed through the cutters by a rotary motion imparted to the fixture. After the work has passed the cutters it drops from the fixtures, and fresh work is inserted as the empty "stations" reach the loading position.

A rough picture of how this is done can be obtained by imagining the fixture as a pair of bevel wheels mounted side by side with their teeth facing. The axes of the gear shafts are arranged at such an angle as to bring the tops of the teeth together more or less at the point nearest to the cutters. The work is fed between the teeth at the "open" side and is carried round to the cutters, by which time it is gripped in rolling contact with the flanks of the teeth. After the cutters are passed, the receding teeth of the gears will permit the work to fall out down a chute. Actually, specially contoured plates are used in substitution for the gears. It will at once be apparent that slots thus produced will not be "flat bottomed," but will be concave to the extent of the radius from the centre of the fixture to







Figs. 31–33 (*Left to Right*).—Two examples of simple milling operations and a broaching job.

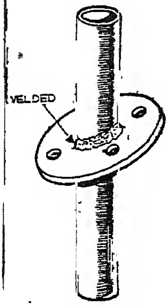


Fig. 34.—An assembly job.

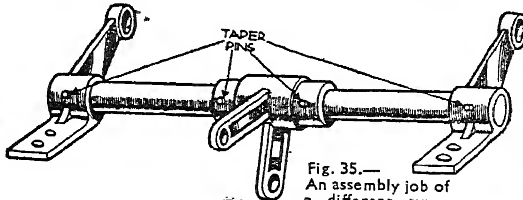


Fig. 35.—An assembly job of a different type.

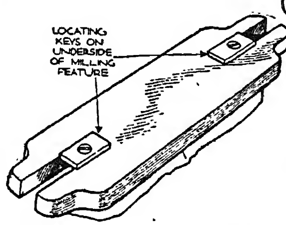


Fig. 37.—Underside of the base of the fixture showing keys.

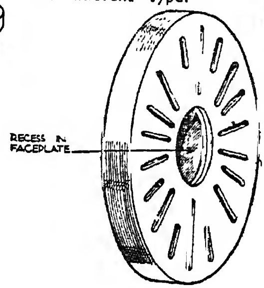


Fig. 36.—Faceplate adapted for mounting fixtures.

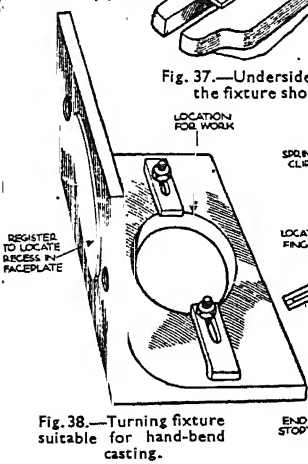


Fig. 38.—Turning fixture suitable for hand-bend casting.

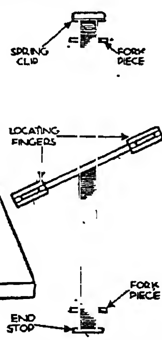


Fig. 41.

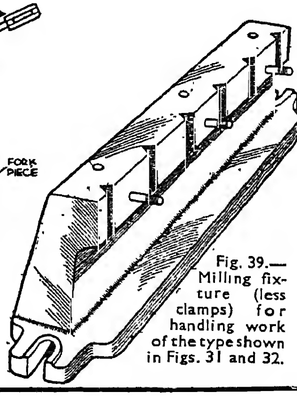


Fig. 39.—Milling fixture (less clamps) for handling work of the type shown in Figs. 31 and 32.

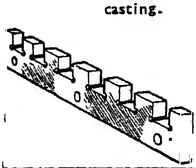


Fig. 40.—Comb plate for use in conjunction with fixture.

the face of the cutter. This fact is one that does not prove objectionable on many classes of work.

Where a fixture is intended to be mounted on the faceplate of a lathe, it is usual to provide a means of location to ensure that the fixture will be correctly positioned without having recourse to the use of measuring instruments each time it is fixed in place.

The common method of doing this is by having a shallow recess in the face-plate, as illustrated in Fig. 36. As this procedure will affect the usefulness of the plate for general work, it is better if a spare faceplate is so treated. Such a plate need not be slotted, a plain one will serve the purpose admirably, and most fixtures can be designed in such a manner that the fixing holes can pick up a pair of studs screwed into the plate. The fixture can, of course, be made complete to screw on to the nose of the lathe, but this will probably involve the inclusion of a balancing medium, which will mean increasing the total weight unnecessarily. Smaller fixtures of a compact nature might well be so mounted, but the less cumbersome method usually will be to fit them with a taper shank, to fit into the nose of the lathe, and provided with a drawbar for extra security.

Mounting Fixtures on Slotted Tables.—The usual method of locating a fixture on machines having slotted tables is seen in Fig. 37. The short keys at either end are seated in shallow keyways, cut in line and secured with screws. Where the base of the fixture is short, the key can run the whole length of the distance between the bolt slots. The keys should be made to fit the slots with a clearance of about 0·001 in. A heavy fixture might require to "pick up" two or more slots for purposes of bolting down rigidly, but it is not necessary to provide keys for each slot. It may be that for the performance of a second operation the same fixture would suffice if turned at 90 degrees on the table. In this case additional lugs and keyways would be provided in the appropriate positions and the keys transferred between the operations.

Circular tables for use in conjunction with horizontal or vertical milling machines are centrally counterbored as on the faceplate illustrated, thus enabling fixtures provided with male registers to be located centrally thereon.

Turning Fixtures.—A turning fixture suitable for mounting the bend casting while performing the second operation, consisting of turning, facing, and screwing, is illustrated in Fig. 38. This fixture is an angle bracket, having a male register on the back face machined to a "push fit" in the female register in the faceplate of the lathe that it is intended to be used upon.

The centre distance of this register from the work-locating surface is made to correspond to the requisite height from the surface of the previously machined face to the centre of the screwed portion. A hole is bored in the horizontal surface of the fixture (as drawn) central with the back register. This hole receives the spigot on the bottom face of the bend, and the fit should be such that there is no slackness, but at the same time the work must be easily inserted and removed.

When the fixture is made from a casting, there is no need to machine the entire surface about the hole, but provision can be made on the pattern to leave a shallow boss round the hole, which is faced to provide a seating for the bottom flange. If this is not done the casting may have a shallow counterbored portion slightly larger than the diameter of the work. The mouth of the hole is slightly chamfered to provide an easy entry and to ensure that the flange will seat positively.

A pair of sliding clamps having "heels" affords the means of securing the work in position. The studs should be so positioned, and the slots in the clamps made long enough, to permit their being slid towards the respective edges of the fixture to enable the work to be inserted or removed without taking the clamps from the studs. Light coil springs should be interposed on the studs between the face of the fixture and underside of the clamps.

A fixture of this type may be built from bright mild-steel plate, the back being attached to the base by means of flush-fitting "Allen" or similar cap screws and dowel pins, and the webs attached in the same manner. Where the work is of a light nature or of small proportions and the fixture consequently of small dimensions, a shank made to fit the nose of the lathe and fitted into the back of the fixture could form an alternative method of mounting on to the machine.

A fixture of this description may be modified to handle a variety of similar

work. This might involve alterations in the clamping method described, and perhaps the inclusion of locating strips to correctly line up flat machined edges on the work.

Milling Fixtures.—A milling fixture is seen in Fig. 40. This is made from a casting, the back of the vertical portion being heavily webbed to provide the necessary rigidity. The casting is machined on the base and provided with keys as already described in line with the holding-down lugs. The top face of the casting and the side square with it are machined, and the vertical surface, in which the vees are cut, overhangs the remainder of the vertical portion so as to provide ample clearance for parts having long shanks. In many shops the type of work which this fixture is intended to handle is of a constantly recurring nature. Therefore in designing such a fixture it is advisable to make its scope of application to cover as wide a range as possible.

The vee slots are, of course, cut to an included angle of 90 degrees and are of equal depth. A stud is placed between each pair of slots so that the two adjacent parts, when in position, are bridged by a single flat clamp having a central hole. To assist in reducing the time required for loading and unloading, the centre hole in the clamps may be slotted out to one side, or, where the centre distance between the vees in the fixture will permit, "keyholed" to allow the clamp to be removed while the stud nut remains in position. In arranging the centres of the vees care should be taken to keep them as close together as possible in order to reduce idle cutting time to a minimum.

The work would be machined from square bar material and the milling performed in two operations. With such work, therefore, it is necessary to make some provision on the fixture to position the parts to ensure that the milling is correct in relation to the sides of the bar. It is presumed, of course, that the shanks of the parts will be machined, with reasonable accuracy, centrally on the bar, as it is from the sides that the location will be taken. A hardened-steel "comb plate," as illustrated in Fig. 40, is attached to the top of the fixture for this purpose with bolts or screws, and further correctly maintained in position with regard to the vee slots by dowel pins. The slots in the comb plate are made to suit the width of the bar material used for the manufactured parts, and there should be a fair gap left at the bottom of the slots for swarf clearance. For the same reason the comb portion could with advantage be raised, by means of a step at the back, to facilitate cleaning.

Broaching Fixtures.—The greater proportion of broaching work consists of cutting splines, squares, or keyways in circular blanks, and, therefore, the necessary fixtures are of a simple nature. An adapter which will enable the part to be centralised in relation to the axis of the broach is all that is usually required. When, however, the work is similar to that shown in Fig. 33, it is necessary to make provision for locating from the smaller boss of the lever.

Surface broaching is an operation of an entirely different character, and work to be handled by this method will demand provision of fixtures similar to those used for milling operations.

Fixtures for Assembling.—A fixture for handling the welding assembly illustrated in Fig. 34 is shown diagrammatically in Fig. 41. Such a fixture could be built up on a flat base, but the construction would be simplified by building up on a round bar. A bar of suitable proportions would be shouldered down and threaded at both ends, and stout sheet-metal fork pieces drilled at the lower ends to pass over the larger diameter and the centre between the fork and the hole being such as to raise the washer, forming the flange, clear of the bar. This washer is located between strip steel fingers riveted to the ends of a U-piece, which is welded at the base to the bottom of the bar in an appropriate position.

A piece of flat steel, drilled at one end and bolted to the shouldered end of the bottom bar, forms an end stop for the tube. The flat spring clip, the purpose of which is to maintain the end of the tube against the stop, is similarly attached to the opposite end. After the flange has been "tacked" in position on the tube, the assembly is lifted from the fixture for completion of the welding.

LATHE WORK

Types.—Lathes are usually divided into three main classes: the centre athe, the capstan lathe, and the turret lathe. The main difference between a centre lathe and a turret or capstan lathe lies in the construction of the tail-stock. In the normal centre lathe this part consists of a body sliding upon the bed of the machine and capable of being clamped in any desired position along its length. This body carries a movable slide actuated by a hand wheel which has, in the end facing the head-stock, or rotating member of the lathe, a tapered hole to accommodate the centres or drills.

A turret lathe has moving along its bed a body which carries a rotating member, termed the turret, which can carry many drills, centres, or other special tools, any one of which can, in succession, be brought to face the head-stock.

The capstan lathe has a similar revolving head or turret to carry tools, but this s not mounted directly upon the bed, but upon a sub-bed or, as it is usually termed, a saddle.

In the normal centre lathe there is only one cross-slide tool and one axial tool, but the range of operations can be increased by the use of a four-square tool post on the cross slide and a turret attachment on the tail-stock. The vee-ways bed or prismatic vee-ways is now generally adopted in this country, together with an all-gear head and unit drive. The advantages of the vee-ways bed over the flat-ways bed are many. Any wear that takes place on the sliding surfaces of the tail-stock on the flat bed considerably affects the alignment of the lathe for parallel turning. In the vee-ways bed wear does not affect general alignment, only centre height.

Unit Drive.—The principal forms of unit drive are: "the clutch-operated gear-box drive"; "the underneath-countershaft drive"; and "the bench-countershaft drive."

Some useful points in unit drive are that the machines can be placed in line or in such a position to suit the general lay-out of the shop, and not set in a position on the floor to suit the overhead main shafting. Staggering, as is done with capstan and turret lathes to save floor space and for bar-feeding purposes, can also apply to centre lathes, and lastly, unless there is a failure in electricity supply, any breakdown that occurs does not affect the whole plant, but possibly only one machine.

So long as the motor is kept free from dirt and metal turnings, the unit drive to a lathe, and all machine tools for that matter, has proved a big advancement in every way. The short distance between the motor and the geared head-stock, with the probable slip of belt, has been overcome by utilising one or a series of endless vee-belts of special rubberised composition, the number varying according to the horse-power transmitted. Vee-belts should be just tight enough to drive the lathe without the motor pulley slipping, for if they are too tight they will cause loss of power through excessive friction in the bearings.

Thread Dial Indicator.—Another important addition to the modern lathe is the thread dial indicator for screw cutting. This device permits the engagement of the half-nut at the correct time while the lathe is in motion, so that the tool will follow the original cut. As the lead screw revolves the dial is turned, and the numbers on the dial indicate points at which the half-nut may be engaged, as follows:

(*a*) For even-numbered threads, close the half-nut at any line on the dial.

(*b*) For odd-numbered threads, close the half-nut at any numbered line on dial.

(*c*) For all threads involving one-half of a thread in each inch, such as 11½, close the half-nut at any odd-numbered line.

The chalk markings of the head-stock bearing and driver plate, the lead screw and the lathe saddle for the purpose of correctly engaging the half-nut for screw cutting, are the difficulties which must be mastered in screw cutting. For details of methods of screw cutting, see separate section and also *Screw Thread Manual*, by F. J. Camm, and *Screw Thread Tables*, by F. J. Camm. Capstan- and turret-lathe practice is also dealt with in separate sections.

Turning on Centres.—The essential is to have the live centre running through and the work running freely between this and the back or dead centre without play.

Chucking.—Including comprehensively in this term mounting on centres and all other means of holding and driving, it is essential to have permanency of position; that is, no error in centring, nor fault in gaining a grip by a chuck shall permit the work-piece to deviate from the first location during the progress of cutting. The tool pressure tends to force the piece into a different state, unless the mounting is correctly done so as to resist this influence, which may be the cause of the parts touching the centres, or deformation of metal there or in the bite of a chuck. On some roughing operations it does not matter if there is a change after the first cut or two, since the subsequent ones will put things right, but there soon comes a limit to what is permissible, especially if the outline is more complicated and the various surfaces are interrelated. Another important matter is the danger of temporary deformation, either by undue tension between centres or by squeezing out of shape in a chuck; then on release the piece will alter and invalidate the truth of certain cuts. The remedies are to exercise discretion in centre mounting and in tightening chucks, and in the latter either to render assistance by a filler or plug device to prevent caving in, or to adopt a different mode of gripping; also to give a positive drive by a peg or other medium so that it will not be necessary to hold so tightly. It is the practice in many instances of the more fragile castings and forgings to somewhat slacken the gripping pressure before taking the finishing passes, and there is a reducing-valve arrangement on some air chucks to relieve the pressure for finishing fragile work.

Inaccurate mounting may be due to faulty centring, chuck jaws that are not true, or back-lash in their fit. Faceplate fixings are very liable to cause errors, because of the chances of deforming the piece through incorrect packing and clamping, and also by the risk of slight displacement occurring. Here again a positive drive by means of a peg or angle-plate bracket is often helpful. Many shapes should have support on three packings, to avoid twisting when the section is not stout enough, and it is also advisable in very particular cases to slacken the clamps somewhat before taking the finishing cuts, as often done with chuck jaws. The clamps should be located over the spots where the packings lie, to give straight-line pressure down to the faceplate, otherwise the section may bend or twist. Bits of paper, card, rubber, emery-cloth, etc., are useful to lessen the risk of work skidding.

Lathe Centres.—Various differences are apparent in the centres requisite for a range of lathe work. The normal style has a 60-degree angle, is hardened and finished by grinding preferably with a portable outfit held on the slide-rest. Variations from this angle occur only in special cases, such as very heavy objects, which may go on a steeper angle, and when the sample is a pivot or other detail demanding a certain angle to which the centre must conform. For some fine operations, including those on precision bench lathes, a reduced diameter is essential, for convenience of tool manipulation and good visibility. The cut-away centre is also useful for a similar reason, but more valuable when facing down ends, and particularly to allow a file or polishing stick to clear over the end of small diameters. Some lathes with front and rear cutting equipment have centres with both sides flatted to allow tools to act freely.

High-speed steel centres are extensively employed, notably because of the increase in speeds since the advent of the tungsten-carbide tools and the early deterioration of carbon-steel centres from the heat generated. Two systems are applied, one the butt welding of a high-speed tip to a shank, the tip being long enough to allow of repeated grindings; the other the Wearden & Gylee socket with renewable insert (the point being also of half-round or square type, if desired) driven into the tapered hole, and ejected by a drive rod through the hole. The socket is of case-hardened steel. Tungsten-carbide gives long-life tips, which are made very small, and the tipped centre can be purchased, or tips only, several of the makers of tungsten-carbide supplying these items.

Anti-friction centres take heavy loads and high speeds in an economical manner without wear or heating, and they can be closely adjusted to the work without risk of trouble arising, thus giving better chances of accuracy and freedom without vibration. Many designs are supplied, some with ball bearings, others with taper rollers or a combination of both.

Solid centres for hollow work are either of moderate diameter or considerably enlarged, a good idea being to have the choice of two or three on an arbor running loose with the pipe. For pivots and pointed spindles the hollow centre comes into use, and when flatted enables filing and polishing to be effected freely. Parallel or tapered holes are also put in certain centres for special support purposes.

Drilling Pads and Chuck Arbors.—Arrangements for drilling in the lathe must comprise support against the tail-stock spindle, or alternatively the holding of a chuck there. Pads are small for little articles, or to allow for overhang of parts; or they may develop into moderate-sized faceplates with a few slots for bolting down awkward subjects that cannot be held by the fingers only. Small angle-plates also go against these larger faceplates, to receive shapes which will not bed otherwise. A little plate may conveniently carry a vee-groove, for taking pins, etc., for cross drilling. To permit of sensitive hand-feed a small plate can be mounted on a stem which slides in the hollow arbor, affording delicate feel for fine drilling or countersinking. Or the plate may be fixed to a tube sliding over the arbor. Regular vee-pads are formed with round or rectangular bodies. A swivel head is sometimes used to enable the work to be inclined. Although clamping can be dispensed with in a great many instances, plates or vee-pads are sometimes equipped with clamping strips tightened down by knurled screws. For precision drilling at the live head a special vee-block saves time, having a hole dead central with the ground vee so that an indicator applied inside will show whether the block lies true before strapping it to the faceplate by clamps pressing on the ledges. Other ideas are, to make the block circular and indicate on the exterior; or to hold it in an accurate jaw chuck.

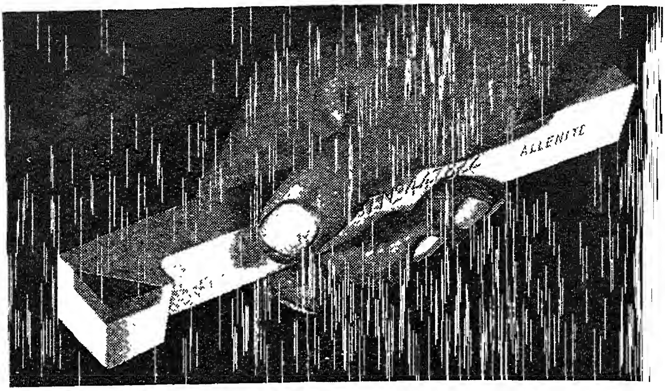
A lot of drilling and reaming from the tail-stock does not require a chuck, the drill resting against the centre whilst held by a carrier, or a proper drill-holder if the shank is taper. Medium and small drills are more conveniently applied by a chuck, and this fits on an arbor going in the tail-stock spindle. Should there be a considerable amount of drilling and reaming, with frequent changes, a quick-change type of chuck is handy, disengaging the shank or socket instantly. Depth of penetration will be observed from the graduations which should be on the spindle; or a stop device can be devised by projecting a tool shank from the slide-rest to arrest the chuck at the predetermined distance.

The fine drilling, reaming, countersinking, counterboring, etc., which are regularly carried on in the precision bench lathes, need very sensitive feed, and a lever-actuated tail-stock spindle supplies this, or else a plain spindle slides through two bearings under the coercion of the fingers, with a stop-collar for setting the length of movement. Quick changing of the various little drills and other tools comes from use of an open tail-stock, lined with hardened half-bearings, into which the successive spindles are dropped, pushed along, and removed, a stop-collar or screw being furnished. Finger feed and that by lever are alternatives.

A class of centring is that of large pipes, castings, or forgings, which may be beyond the capacity of the enlarged centres mentioned previously. Bridging or plugging is resorted to, then. A strip of hard wood will serve for a brief period, but properly one of metal must be fitted to last, and it is filed or ground to jam into the bore, with or without a shoulder contact. A disc is sometimes chosen. The spider is a convenient shape, possessing three arms which automatically centre it, and better still the adjustable form, giving capacity for different sizes and facility to throw the boss to the central position by screws.

Carriers or Dogs.—The normal mode of rotation between centres is by means of a dog affixed to the work with one or two screws. In special cases an automatic grip is applied by an eccentric or rocking motion, which causes a serrated pad to seize the shaft. The main distinction in carriers is between straight- or bent-tail types, the first requiring a catch-pin on the driver plate, the other going in a slot in the plate. The relative merits are that the bent-tail drives backwards as well as forwards, which is a convenient feature when screw cutting, as there is no catch-pin flying around whilst the spindle is slowing down at work removal; but there is a risk with the bent-tail that it will spring slender diameters.

Catchplates.—These are just sufficient in size for their function, so as to give minimum obstruction to sight and manipulations. For some bench lathes a combined draw-in adapter, centre, and plate is supplied, but otherwise a plate is


ALLENITE

fitted to the spindle nose. For screw cutting and relieving a dog must be tied to a driver-pin, but properly a fork with binding screws is attached to the plate; this also occurs on the sub-spindle speed reducers which enable coarse pitches (as well as relieving) to be dealt with.

The objection to the one-sided drive of the ordinary catchplate is that the pressure causes influences which may bend a slender spindle or interfere with accurate cutting on heavier stuff. The Clements driver obviates this, imposing equal stresses on opposite sides, and consists of a loose-slipping plate, the pins seating equably against the head and tail of the carrier before the pegs in the catchplate begin to transmit the drive. The principle appears in several recent designs for multi-cutting lathes, and there is another idea, that of a transverse pin with sloped flats on opposite sides of each flank, the pin being free to twist until the flats have settled uniformly.

Chucks.—Chuck-work, as distinct from centre-work, involves the consideration of a great variety of holding appliances, which during the past quarter-century have been elaborated into hundreds of modifications, arising from the necessity for rapid handling, and of dealing with shapes that do not lend themselves to a grip by ordinary jaws or clamps. There are variations based upon the primary faceplate principle, which becomes a fixture when suitably equipped with blocks, stops, fixed or adjustable locating surfaces, clamps, balance-weights, etc. The jaw chuck is furnished with special false jaws or slips, packings, stops, floating actions, indexing details, and clamps to assist the ordinary bites. Collet chucks incorporate special collets, liners, locating agents, swivel motions, indexing devices, rocking or pull-back or push-out clamps, etc. In addition many schemes are devised to ensure accurate setting in chucks such as aligning plugs or bushes, and there are mechanisms for convenient or rapid loading or unloading, often without having to stop the lathe. Continuous production is obtained in certain other ways, such as by magazine feeds giving constant flow to a chuck, and by having duplicate loading spools, or arbors that are stripped, cleaned, and reloaded during the time that the lathe is occupied with the other unit. In mandrel or arbor chucking immense changes are also noticeable. Single multiple holding occurs; forms awkward to drive receive special fittings; and quick handling obtains from clamping features actuated by the setting up of the tail-stock spindle, which carries plugs or collars, and generally a ball- or roller-bearing thrust. Pneumatic operation has been a vital feature in chucking practice, revolutionising methods in several directions, and electric power also appears in some examples. The magnetic chucks facilitate a considerable amount of lathe work which cannot be done so easily in any other manner.

The Principles of Chucking.—Three aims are essential in successful holding: (1) to locate so that the piece will be accurately placed for the purpose; (2) to avoid distortion which would either cause damage, or prevent true machining, owing to alteration of shape after releasing the chucking pressure; (3) to hold with sufficient firmness so that displacement shall not occur during the operations. Requirements (2) and (3) are interrelated, and many expedients have to be resorted to, such as spreading the area of contact of jaws or clamps over a goodly amount of surface, arranging special sorts of supports, and giving a positive drive which will lessen the need for a tight grip. Distortion, practically unavoidable in a large variety of castings and forgings, is countered by partially releasing the pressure of jaws or clamps before taking a final cut. This is a matter of hand adjustment, or in air chucks of the control by a valve which relieves the full pressure to a determined amount. Demands naturally vary as to limits of accuracy, either because of specified limits in turned products which are not subjected to further treatment, or because a grinding or other process follows that will remove slight errors induced in the mode of chucking. Therefore it is often vital to adopt a mode of chucking which will not produce the least distortion, while in other cases such care is not necessary.

The main difficulty in the more fragile or complicated castings and forgings is to effect even tension, so that flanges, feet, lugs, or other details will not be sprung. This is a question of getting the pressure on to thick sections as far as possible, and of supporting in such a way that the jaw or clamp lies above in packing when such can be emplaced. Adjustable peg supports are often employed; sometimes with springs beneath, so that they float up into contact with surfaces that vary in

different components and are then locked by set-screws to act rigidly. The familiar three-point support is efficient in eliminating the risk of warping of the thinner sections.

Chucking parts that have had some treatment is coped with in various ways, including accurately turned or ground jaws or fixtures, and special fixtures where these methods cannot be applied.

Faceplates.—Chucking is mainly divisible into radial and axial holds, represented by the jaw chucks and the faceplates respectively, but the principles are not fixed, since the faceplates can hold by radial screws, and the jaw clamps may have face clamps added, while many fixtures embody both methods. The faceplate is a very adaptable medium for holding all sorts of shapes and adjusting them as desired, and by the addition of an angle-plate will deal with objects otherwise difficult to fasten or locate. The differences in plates concern size, number, and arrangement of holes and slots, and provisions for using poppet screws, jaws, and other items. In the heavier lathes and turret lathes there is no changing of the work-holding agent, for in the first case the heavy plates carry either detachable jaw units or removable jaws, enabling the plain slotted plate to be used with clamps; and in the second case there is a heavily built chuck from which the jaw tops can be removed, leaving the tee-slotted body for ordinary face-clamping or conversion into a fixture, often with one or two special jaw tops brought into action.

The smallest plates are those of bench lathes held in by the draw-bolt, the "solder chuck" having a plain brass face and others a set of tapped holes. A cast-iron plate may be shrunk on the hardened adapter drawn into the spindle, the adapter being with or without a taper hole for the centre.

Angle-plates.—Little plates for bench lathes are furnished with plain or tapped holes; in other cases open slots are made, two or three for small sizes and more for larger ones. The central slot of the base allows the plate to be adjusted radially and tacked with a bolt, after which two others can set through the flanking slots.

Bell Chucks.—The function of these is to hold shapes which are too long to remain secure in an ordinary jaw chuck, though if there is a sufficient number special jaw slips will overcome the difficulty. The bell chuck has the advantage that rough pieces or forgings can be adjusted to run as required or be set eccentrically.

Jaw Chucks.—Several different sizes and kinds of jaw chucks are needed to cope with general work, including one or two drill chucks of light and heavy types, a small scroll chuck, a heavier independent or combination style, and sometimes a heavy independent for rough use and difficult examples which require extra bolting and adjustments. The faceplate fitted with dogs or jaws is an alternative to the last named.

Jaw chucks are broadly divisible into self-centring and independent, and the combination type embodies both movements. Its jaws can be moved separately by screws, or they may all travel simultaneously by scroll, to take concentric positions, or be eccentric for repetition holding. The self-centring, concentric, or universal chuck has its jaws or slides actuated by a scroll, screws, cams, or other mechanism operated by hand or power, or with air or electric movements. The alternative to its use is the collet chuck, of rather restricted opportunity in general lathe work, but of the highest value in special lathes and those of capstan and turret class. The number of jaws in a chuck varies: from two in the brass-finishers' round-body or box-body style, which is fitted with special cut jaws or slips; two in many air chucks; and to three or four in other sorts. In special cases there might be only one jaw, or two arranged in collaboration with fixed blocks of plain, angular, vee, or curved shape to suit the work-piece, and in exceptional instances more than four jaws may occur.

The Independent Jaw Chuck.—Two principal methods of construction are followed, the older system of using screws like those of slide-rests, square-ended and shouldered, passing through a nut at the back of the jaw, which slides in a plain slot, and may also be sunk slightly into the face of the plate to take the lateral thrust better; and the one most favoured, a headless hollow screw of stout proportions engaging in a half-diameter thread at the back of the jaw, which is deeply sunk into the thick body, and has a single- or double-tongue grooving.

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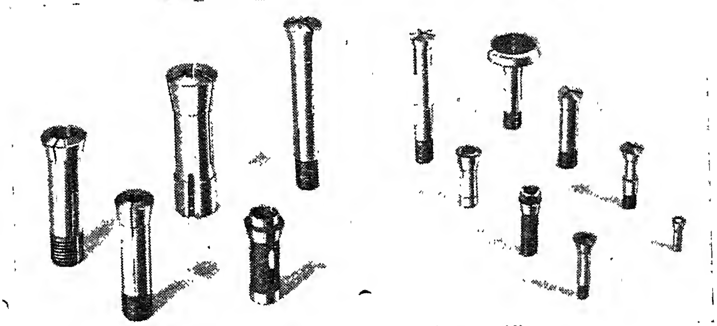

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The Self-centring Chuck.—This is made in many sizes and types and actuated in different ways, but the best is the scroll, giving a powerful and simple action. Mechanically the idea is but a compromise, since the whole width of the thread surface on the jaw cannot make full contact on the scroll at both the large and the small diameters; but by the choice of the best materials—alloy steels—good results are obtained with long endurance. There are two important departures from ordinary flat scroll construction—the Taylor spiral chuck, which has a sloping scroll with vee-thread that can be hardened and ground, also the jaws; and the Herbert "Coventry" chuck, having three eccentric grooves fitting the whole length of sliding pivotal blocks attached to the back of each jaw slide. The motion is limited, but the top jaws can be quickly shifted to different radii by easing their binder screws half a turn and disengaging the serrated fit of the joints.

Spiral Chuck.—The Taylor chuck design permits the hollow scroll to be ground after hardening, and the pinions are also ground. The pressure comes more nearly behind the work, and the threads do not tend to push over and become deformed as with a flat scroll. A spring ring is included in larger chucks to take up back-lash in the scroll. Two-, three- and four-jaw chucks are built, but the last named have but limited use.

Geared Screw Chucks.—The old independent-jaw screw motion is used in a Skinner self-centring chuck, developed into simultaneous action by cutting bevel pinions on the shanks of the screws, so that turning one screw communicates the movement to the two others through the medium of a crown ring. Such designs are made up to 36-in. size.

Two-jaw Chucks.—A brass-finisher's or box chuck has two jaws, the primary use of which is to attach slips cut to shape to take contours, such as occur in all sorts of brass fittings, iron castings, and forgings. It is not necessary to have three jaws for this purpose, and the two will open rapidly to receive a globular or other form. The construction happens to be useful also for plain cylindrical, square, hexagonal, or octagonal stock when the jaws have a vee cut in them.

Standard chuck jaws are limited in scope by reason of their depth of grip and straight shape, consequently there are large groups of parts which cannot be held safely in them. False jaws afford extended surfaces for flat areas, or any contour comprising angles, curves, or a combination of these. Jaws may be similar, or different on each bite. A very shallow hold is frequently essential, to give clearance for facing or turning tools; this can often be arranged by the addition of packing washers, collars, blocks, or studs, to bring the object out with the minimum grip; but considerable use is made of cut slips recessed to the depth of dispensing with packing devices, and capable of being trued or shaped to hold with the most power. Clamps must be added to many shallow-cut jaws to prevent the work from pulling out, if it cannot be sustained by a point centre or a plug or bushing at the outer end. In general practice the clamps can usually be rigged up from the slots in the chuck face, but for continual use a self-contained screw and clamp unit is fitted to the jaw.

Holding Curved Shapes.—Great diversity occurs when dealing with globular, elliptical, oval, and gently curved objects, since it may not be necessary to touch on more than a small portion of the curve, at two or three locations, and a considerable proportion of such samples can be chucked on the necks, stems, flanges, or other parts which go to make up brass fittings, stampings, and various accessories. On some finished contours of a fragile character it may be essential to provide some datum surface—the front or back of a flange, or a lug or other projection, which touches a fixed spot on the jaws or on a packing or stop-peg. Many castings need a sort of vee-block or cradle to locate them before the jaws tighten up.

Packings and Stops.—The support and packing out of things which either demand a certain degree of projecton for machining reasons, or need sustaining to prevent deflection at places where the rigidity is insufficient, are a matter of shaping jaws suitably, or of adding blocks or pegs, or screwed props. A simple instance is that of inserting a peg or screw into a jaw face for an abutment or carrying out a stop independently. One of the screws that fastens a false top to the base will serve as a stop if made with a longer head. A ring encircling the jaws, or lying inside them, makes a good solid support for the more slender pieces, taking care to clean off the swarf after each operation. A fixed stop can be arranged in

the form of a plug put in the spindle hole ; or a ring attached to the chuck with two or three screws, this also showing pegs which give the means of substitution to vary the distance as necessary. They likewise provide clearance for borings to fall through.

Split Chucks.—Fine drills may be held with the least obstruction to the view and operational facility by a split holder and taper nut, or with a bushing system for shank diameters. The body of the holder is tapered to go in the spindle holes ; a quick application device is to finish the body to an enlarged shape and drill up to 60 degrees end to slip over the back centre and seat upon the point. Thus it can be instantaneously placed on and held by the finger grip on the knurled exterior for brief cutting times. The same notion applies to set-screw chucks for centring countersinking, drilling, etc.

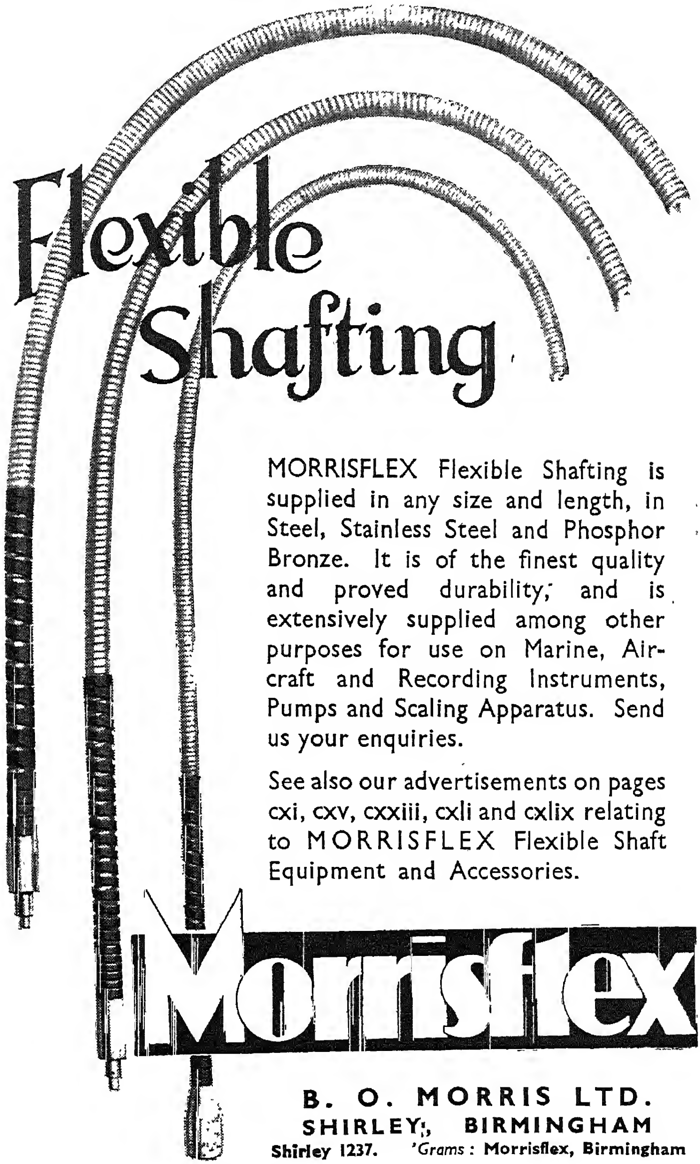
Three-jaw Chucks.—The compact three-jaw chuck with tapered nose is well suited for lathe work (including holding of small rods and tubes), affording good access and visibility. Tightening is by the hand grip, screwing the jaws to and fro, and if necessary giving additional power by a pin wrench set in a hole. The geared chuck is advantageous from the ease of tightening with a strong grip, and the spindle does not need to be held in opposition to the twisting of the body, as in the plain type. Several makes are available, some plain, others with ball bearings to eliminate friction and speed up manipulation.

Two-jaw Chucks.—For heavy service and durability it is best to use a two-jaw screw-actuated chuck, which holds by interlocking surfaces, and in most types includes positive drive by a floating plate engaging the drill tang, or two side screws are provided to set up against the shank for additional grip. A steel cap is fastened to the front to prevent the body from spreading, and in some designs the side screws are put into this. The interlocking-jaw method gives such a powerful bite that it is often chosen for taking bar for cutting-off operations, the chuck then having a recessed back to attach to a backplate, leaving a clear way through the spindle.

Quick-change Chucks.—A very useful style, especially when doing runs of production work with drilling, step-drilling, boring, counter-boring, facing, and other cuts, is the chuck which frees the drills or socket or boring-bar by an instantaneous disengagement of a key or tang or steel balls in various types. The release may be effected whilst the spindle is in motion. Ordinary drills and other tools are accommodated in a sleeve or collet. A floating motion may be the result, beneficial in allowing for faults in machine alignments or lack of correct relationships due to work-holding methods, or inaccurate bodies, shanks, etc. This motion is valuable for reaming and other secondary operations, taking the place of the usual floating holder with cross-pin.

Collet Chucks.—Three principal requirements exist in regard to collet chucks. (1) The holding of small rod and-tubing in metal and other materials accurately in the precision bench lathe, also discs and wheels. (2) A similar demand for tool-room and other lathes of a larger size, with, in either case, simple hand closing by means of a wheel, or quick hand control by a lever closing-sleeve and fingers. (3) Elaboration of the collets for chucking blanks, castings, and stampings which need larger collet hoods and collets, and frequently special features for holding pieces by sliding or rock clamps. Requirement No. 3 is seen in its highest developments in the capstan and turret lathes, and various automatic machines, with air operation and auto chucking and feeding arrangements.

For the small lathes and tool-room lathes the collet mechanism is used, and the collets should not be used to hold diameters not closely approximating to the bore size. Length of bite should be about twice diameter. Tool steel is the proper material to use, hardened and tempered, after which the collet is ground true inside and out. A convenient mode of making is two from a bar, which facilitates some of the machining. A step collet takes a larger size than will pass through the collet, the enlargement being carried along as far as practicable for the purpose of holding short pieces of stock or partly machined specimens. In the latter event the depth of counter boring may be occasionally such as to set the correct distance out for a secondary operation. Collets are also made with taper hole to carry the point centre. Considerable enlargement occurs in the step chucks that have hoods or closers, the collet being recessed out to two or more diameters, as many as eight.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Wheel Chucks.—A set of three wheel chucks will accommodate all standard sizes within the range, which may extend from, for example, $\frac{1}{2}$ in. to 2 in. External-step chucks act in the opposite manner, the collet being a cone of steps, and expanded by drawing back over an expander hood screwed on to the spindle nose. These are for chucking thin rings, bands, washers, tubes, rims, and so on. A similar effect to the foregoing types is obtainable for service of short duration by cutting a hardwood chuck with steps recessed out, or turned on a body, afterwards partly sawn through in three places. Contraction is caused by forcing a metal ring over the tapered exterior, or screwing a ring nut along tapered threads; and expansion is effected by gently tapping in a tapered plug in a central hole or turning in a screw. These wood chucks are convenient for fitting any diameters wanted at the moment, but are not of a permanent character. Ordinarily collets may also be wanted with square or hexagonal holes, being cut with four and three splits respectively.

Front-operated Collet Chucks.—Instead of the draw-rod method some chucks are constructed to close by a hand wheel incorporated in a spindle nose fitting. The Cushman nose-type draws back the collet by a nut cut with bevel teeth for the pinion, which gives delicate control. The body is mounted either by the usual threaded hole backplate, or by an adapter that is shaped to fit the standard long-taper key nose.

Lever Chuck Closers.—Rapid release and closing of either plain collets or those of step form, for repetition work, is provided by the lever-closing system, which also gives uniform tension each time and is fairer to the collets. The motion resembles that common to capstan lathes—a sliding cone acting in conjunction with bell-crank levers to move the draw-back rod, the cone being slid by the hand lever. The tension is regulated as necessary.

Master Collets.—In capstan and turret practice the varieties in bar sections, and cast or stamped unit pieces, require so many kinds of collets that to make one for each would be too costly and wasteful of metal and storage space. Hence a master collet of normal diameter, or of enlarged shape, must serve to close sets of liners put in and quickly fastened by screws. The same applies to much ordinary lathe procedure, when manufacturing has to be done. There is little difference in methods, the screws being placed radially or axially, the latter rendering it unnecessary to abstract the collet for changes. With radial screws the liner is shouldered in. For production from bar, push-out collets are considerably employed, as they permit the accurate feeding of the material against the stock-stop. The draw-back collets are good for second operations where it is necessary to pull back against a shoulder. The stationary collet is a type which has no end motion, and consequently does not move the stock endwise at the moment of closing, thus shoulder lengths can be accurately ensured. A cap at the front locates the collet, and closing is done by the tube, which always forces the collet against the cap.

Liners.—The liners or pads vary in number according to the number of splits in the master collet; there may be either three or four for round stock, while square, octagonal, or oblong sections require four splits and hexagons three. The gripping surfaces are either serrated or plain for round bar, depending on its state; the liners are turned as bushes to fit the collets, drilled for the screws, then sawn through ready for finishing the bore.

Enlarged Hoods.—The normal capacity of a collet is determined by the bar that will pass through the actuating tube and closer, but when discs, wheels, sawn or forged or cast blanks, and an enlarged collet are to be machined, a hood fitted with a ring-nut or liner embraces the collet. The latter is alone or carries liners, corrugated for extra power, or plain, being attached by axial screws. The endwise setting of the work-piece may depend on its touching the bottom of the collet or liner, or meeting the front face, but plugs or stop-screws are often inserted in the front of the hood for an outlying flange of the piece to come against. Or a complete ring can be fastened on if the flange is slender and liable to deflect under the tool pressure. Abnormal capacity is sometimes afforded by making the liner of hood shape, spreading out after it leaves the collet, and being bored to hold discs, etc., which may be as large as the exterior diameter of the closing hood itself. This idea is suitable only for light cutting. A pilot bushing is a necessity in some collets, to align the pilot end of a boring or other bar, and long collets

may need a bushing or coned ring at the inner end of the chuck to centralise a tube or shell accurately.

Chucking Screwed Components.—The draw-rod or push-rod of a collet-type chuck enables nuts, threaded collars, washers, flanged fittings, nozzles, etc., to be fixed instantly after running them in with the fingers. A number of differing methods are available, according to the shape of the work and whether the screw is inside or outside. An adapter is made to screw the object over or into. There is an additional necessity of aligning the article by means of the closely fitting push-out rod to prevent it from lying askew at the start or moving over when being turned. Another application of collet chucks, that of operating expanding arbors, will be considered later in connection with arbors.

Adjustable Adapter Hoods.—For very accurate results a two-piece adapter hood may be employed, one portion being screwed on the spindle nose as usual, the other part socketed over and fastened to this portion by axial screws going through clearing holes. The socket joint gives freedom for a float movement, which is produced by axial screws passed through the front unit, after which the axial screws are set up tightly. In this manner adapters may always be kept concentric.

Air-chucking Practice.—Elimination of hand exertion in the air chucks enables output to be maintained at full pressure, the question of fatigue not coming in. A mere touch upon a lever or pedal causes gripping or release, and many sorts of objects can be inserted or removed while the spindle is revolving at full or reduced speed. The degree of pressure can be regulated to suit strength of work, or a reduced pressure may be had instantly to give a less hard squeeze for a finishing cut. Two-, three-, or four-jaw chucks are made for different requirements, and collet chucks in several forms. In addition, various pull-back lever and finger chucks occur for taking articles which cannot be held by radial grip. Fixtures also employ air power in certain cases, and arbors (as we shall show later) are well suited for this facile mode of tightening. Some additional items may be included on air chucks, similarly to others, such as packings, stops, locating plugs, discs or rings, pilot bushings, and driving pegs.

In the Alfred Herbert chucks an air cylinder is mounted above the chuck, and moves a ball-closing sleeve by means of a lever. The double-acting piston has this lever pivoted in its middle, and the control valve lies on top of the cylinder. A one-piece collet is fitted in the smaller chucks, and loose pads or jaws in the larger.

Chucks with End Cylinders.—The varieties of chucks that are actuated by a cylinder located at the tail of the spindle include spring- or hinged-collet types, sliding-jaw concentric chucks, combination designs adjustable similarly to hand-operated combination styles, compensating-jaw models which possess floating motion to accommodate themselves to work on centres, two-jaw indexing or valve chucks, and the special finger chucks made to order. A draw rod goes through the spindle, or a tube in some instances where it is needful to pass work at a distance beyond the jaws or to run a pilot end through.

Sliding-jaw Chucks.—The favoured way of moving jaws is with bell-crank levers or toggles, pulled by the sleeve on the draw rod. The bases thus controlled are T-slotted and serrated to carry the top jaws, which can thus be adjusted or reversed on slightly loosening the screws. Standard hardened reversible jaws are furnished, or soft blocks to be bored as desired. A pilot bushing is sometimes used, but, if necessary, great depth of penetration may be had by fastening the draw rod to a long tube connecting to the sleeve. The standard stroke of the double-acting piston is 1 in., but special needs may be met by making a cylinder for longer stroke. The packings are self-adjusting by the air pressure and need no hand correction. The auxiliaries are: a stop valve, reducing valve, pressure gauge, and lubricator, the first-named being used to cut off air while adjustments are being made. Either a lever or a pedal gives control, depending upon the character of the work dealt with.

Two-jaw Chucks.—The more suitable nature of the two-jaw chuck for certain kinds of products results in various makes of chucks of similar toggle mechanism, either concentric type or with adjustable jaws for odd-shaped parts. Another motion has a cylindrical rack on the end of the draw rod, rotating a pinion on each side of it, each pinion meshing with a rack cut on the slide base. This gives

a long stroke. The top jaws are adjusted independently by screws, and dove-tailed and drilled to hold the slips. In indexing chucks the jaws stand out some distance in bracket form and receive ball-bearing spindles with notched index plate on one end, and a locking catch. The false jaws are secured by screws.

Four-jaw Chucks.—These are better for certain duties, and either are of normal concentric pattern with adjustable top jaws or act on a duplex principle. Each opposing set of jaws in the latter moves independently, and square, rectangular, oval, elliptical, or irregularly contoured sections are properly held. A duplex cylinder with two pistons, one within the other but of equal areas, is used.

Combination Chucks.—For general purpose the combination style is handy, just as it is with key chucks. The bases have headless screws by which the master jaws are regulated for setting, after which they all work in unison. Considerable variation is thereby possible to cope with differences in cross sections and irregular pieces.

Floating Motion.—When a piece is located by a plug or put on a point centre, air power is rapid as a means of applying the drive. The necessary compensation of pressure is given by a spherical connection allowing the jaws to settle themselves by from $\frac{1}{8}$ in. to $\frac{1}{4}$ in., in different sizes of chucks, before tightening. Eccentricity and irregularities are thereby compensated for. Many classes of centre work can be expeditiously handled in this way, especially when the tail-stock has air control to its spindle.

Finger-type Chucks.—Finger-type chucks are also supplied with compensating mechanism, so that the equable pressure is imparted, after the article has been located on a spigot, or inside a socket, or by some other medium. Very accurate second operations are thus ensured. A tandem cylinder sometimes actuates three floating fingers to pull a part down against the faces of three jaws, which then tighten on to its rim. This is certain for thin items where the jaw grip is very slight because of the width available, or the fact that a corner of a bevel only can be touched, or for reasons of fragility.

A good many kinds of fixtures embody clamps which straddle across the piece or seize it at two or three spots, and compensating movement is essential to gain uniform tightening or avoid distortion.

Arbors.—The arbor or mandrel supplies an accurate method of locating and driving pieces by holes or recesses, and there are many variations in types for general or special requirements. Some hold only one size, others possess a slight expansibility to meet differences in normally standard bores, yet others will handle a considerable range of maximum to minimum diameters, either by substitution or expansion sleeves on a body, or by the forcing outwards of pads. The original function of the mandrel was to carry a bored object for finishing exterior portions concentrically, but the scope has been extended by the use of several kinds of expansion-pad designs which chuck by rough-cast or forged interiors. A compensating motion sometimes equalises the grip near each end. Since the advent of the multi-cutting lathes, quicker ways of arbor chucking have been devised, not only by making air cylinders effect the tightening and release, but by using stump arbors that instantly take the work for a short distance in each end. Time is also saved by running a set of arbors, two or three being loaded at the bench or stand during the period that another is in the lathe. Some proportion of work is mounted on very shallow or stump arbors, but the driving must generally be done by some extraneous agent, such as a peg, or clamps, or chuck jaws. If the number of pieces warrant it, an expansion stump may be employed, either to drive wholly or partially, or for the purpose of ensuring a close fit in slightly varying samples. Eccentric arbors, both of ordinary long form and stump, are used considerably. A make-up is sometimes arranged by turning a piece of stock to receive the eccentric, fixed by a key or set-screw, then holding the arbor in the independent-jaw chuck, offsetting it as desired. Screwed mandrels are essential for holding nuts, collars, brass fittings, etc.

Standard Solid Arbors.—A good standard arbor is accurately centred, hardened, and finished by grinding, with slight taper of about 0·005 in., the size being marked at the large end. The centre recesses must be lapped smoothly before attempting the finishing, otherwise changes will occur in time. Protection is also imperative to prevent hammering or pressing from causing deformation, and this is done by sinking the centre-drill well down, then making an enlargement, so

that no effects reach the vital spot. To deal with a variety of washers, rings, collars, narrow bushings, and so forth, the stepped arbor is valuable, two or three providing a good range of diameters. If it is not convenient to try forcing the two into a tight fit, the sleeve can be split and tightened with a screw at the spot where the washer obtains sufficient friction for machining or a brass-tipped screw may be fitted to the sleeve instead. Another idea, if a lot of facing has to be performed, is to make the mandrel with a series of shallow grooves, and when the piece has been forced along suitably, the tool can go past the edge of the bore into the relief space afforded by a groove. This gives finish right to the corner and avoids the risk of inadvertently ploughing into the mandrel.

Auxiliary Drive.—When the frictional fit alone is insufficient to drive against the cut, or the article cannot be forced on tightly enough without risk of fracturing it, a driving pin can be projected from the catchplate or faceplate to come against an arm in the work or a hole in the web. Another method of getting the same result when a close approach to the catchplate cannot be secured is by a split sleeve being fixed tightly to the mandrel. If needful, it can be transferred to the other flank, thus enabling the facing to be done down each side in turn. Other kinds of drive will be seen later in connection with arbors.

Expansion Arbors.—Two advantages are derived from expansion types—varying bores can be held and the faces may be overhung to leave a clear pass for the tool. A firm, reliable result is ensured by the split-bushing method, expanding when the tapered mandrel is forced into it. A set of bushings will cope with a moderate range of bores, and the outside could be stepped in order to provide a locating face for squaring up washers which might otherwise lie slightly askew. Simple bushings are cut through at one side, and partly so at two other places, if the thickness demands. Flexibility is increased by grooving the body or by cutting several slits from each end alternately. The larger the bushing the greater the number of slits. The exterior is sometimes serrated for gripping in rough holes. Stump arbors may be screw expanded.

Blades or keys sliding up taper grooves afford adjustability and means of tightening when the large end of the mandrel is driven or forced, and if two or three steps are formed, considerable capacity is obtained, such as from $\frac{3}{8}$ in. to 1 in., or $1\frac{1}{2}$ in. to 2 in., or 3 in. to 4 in. The largest sizes have the keys worked by a nut and screw.

Air-operated Expansion Arbors.—Many kinds of expanding arbors are actuated by a draw-back rod and hand wheel at the spindle rear, but the air cylinder affords instant and effortless action. In some instances a pull-back motion is used, in others a push-out is preferred. Construction depends upon whether the components are bored first or come rough-cast or stamped. Length of hole also makes a difference. A long body, for example, will be held on a split sleeve, made flexible with a series of alternate cuts. This would be satisfactory for drawn tube and neatly forged or cast units (as well as finished bores), but when interiors are rough and variable in longitudinal and circular shape, three cylindrical on rectangular pads localise contact and furnish greater range of expansion, being moved by cone or cones. This is the class utilised for shell forgings and many like objects—liners, sleeves, bushings, pistons, and so forth. The pads are duplicated for long holes of uniform or stepped diameters, and duplex push-out tube and draw-rod combination will compensate the grips to tighten equably.

Relatively short specimens are mostly put on stump arbors, that is with no support from a point centre or hollow centre. The expansion bush is operated either by single or double cone, or the part screwed into the adapter on the spindle nose is extended into a split stump opened by draw-back motion, or push-out. A safeguard against deforming or fracturing the sleeve is arranged in these outfits by allowing the head of the draw-back bolt to touch the end and positively check further movement, with similar traverse before arrest. The threaded collar gives a locating face.

Combined grip and location of a larger object is often afforded by fixed blocks sustaining the shoulder of a casting while the arbor tightens in the bore. The radial-pad device is frequently applied to short arbors, three plungers being forced out to a cast hole; location is provided by the end of the body.

In production work the need for reducing chucking times, and also of getting in the most intensive cutting consistent with accurate results, has an effect on

arbor practice, namely, that of gaining instant and positive drive. When there are a lot of tools acting simultaneously, the frictional transmission we have hitherto noted may not be adequate, so use is made of keyways, splined bores, clutch ends, and dowel-pin holes. If none of these exist, a hole or notch may be specially cut in an end. Furthermore, time is saved in placing the arbor by making it with flatted or squared end to slip into a floating plate on the catchplate, imparting balanced drive; or a loose cross-pin goes in grooves in the plate, and has flats at opposite sides, sloping 15 degrees each way, and these float in the grooves until equal effort is gained. A force-fit key drive may suffice to prevent endlong displacement, or a push-fit only can be retained in the manner represented, the sleeve being slipped over and taking the centre, which is fitted in a ball-bearing spindle. The sleeve is knurled for quick handling.

Floating Jaw Chucks.—Some of the longer articles go on stump arbors attached to jaw chucks which offer instant means of gaining firm drive; but unless the part touched by the jaws happens to be concentric with the bore, float is essential to let the jaws settle with uniform pressure on eccentric and irregular spots. The air compensating chuck meets this demand, so does the floating scroll design where the outside diameter of the scroll has been reduced to let it have a little freedom in the body.

Piston Arbors.—A special class of stump arbor deals with pistons and other shapes to be located by a rim at the mouth, and held by an internal clamp, or else driven by an inside dog and run on the back centre. The clamp will catch against the gudgeon-pin bosses, or a pin through the draw-rod end is the mode of tightening.

Ring Arbors.—The clamp arbor may take concentric rings, or eccentric piston-rings, when the shoulder is suitably turned. Or, without turning a shoulder, the exterior of an eccentric ring may be set concentrically by putting a shouldered gauge-ring over. Some types of thin washers are also chucked on flange arbors, and a batch can also be strung and clamped on a longer surface for turning the diameters. If required, a vee-point tool may perform chamfering, feeding it into the line between each pair, and so chamfering two simultaneously.

Holding Tapers.—The differences in this class of chucking concern general and manufacturing procedure. If individual examples are handled, the forcing may bring the piece anywhere along the arbor where it happens to fit sufficiently tight, but when sets of tools operate from definite positions each time, the location upon the arbor must correspondingly be repeated similarly. This entails finishing the taper holes all alike and often having a shoulder, or lock-nuts adjusted; when the drive is by a key or two the question of obtaining a tight fit for rotation does not arise, and in many circumstances also a single- or double-peg drive will be the method. Two modes of ensuring close fit in bores that vary slightly are: to have an expansion stump, or to move the taper arbor as required until it seats accurately in the object, itself retained by a shoulder. The latter scheme may be applied to a boss, the thin flange of which bolts to a faceplate, and the arbor retires against the opposition of the spring, until the flange is bedded. The arbor also carries a pilot bushing to align the bar which holds a boring cutter and chamferer for the mouth. Mention may be made that many stump arbors are extended to form steady-pilots entering holes in knee tools and like outfits coming up from the turret.

Lathe Terms

Apron.—The front of a saddle containing gears and controls for the screw cutting and feeds.

Attachments.—Extra fittings put on to enable special operations to be performed.

Back-gears.—Used to gain power in a head-stock when the cutting resistance is excessive.

Bed.—Casting on which the heads and the saddle slides are mounted.

Bell Chuck.—A hollow chuck to hold wood or to take bars which are pinched with radial screws.

Box Tool.—Employed in capstan and turret lathes for turning to uniform diameters. Vee or roller steadies support the bar opposite the tools.

Cam.—A vital part of many automatic lathes controlling the motions.

Capstan.—A revolvable tool holder, with index to locate the various tools in line with the lathe spindle.

Carrier or Dog.—Device which, pinched on a shaft or bar, enables it to be rotated on the centres by the catchplate.

Catchplate.—A disc on the spindle nose driving a carrier locked to the work.

Centres.—Usually made to standard angles of 60 degrees to run work on between the heads.

Change-gears.—Vary the speed ratio between spindle and lead screws to enable screws of various pitches to be cut.

Chaser.—A tool having several threads on its end to cut or finish screws.

Chasing Saddle.—Applied to certain lathes; it cuts threads by the control of a leader or hob-screw.

Chuck.—A work-holding device, having jaws that slide or rock or spring to hold concentric or irregular work.

Collet Chuck.—Employed for repetition work; holds one size, but adaptable for other sizes and shapes by substitution of different collets or gripping pads.

Compound Rest.—Mounted on the bed to impart movement, in two directions, to the tool.

Coolant.—Suds or oily emulsion flooded on work to cool and give smooth finish.

Cutting Off.—Or parting, effected with a narow tool, after components have been machined from bar.

Dividing Plate.—Drilled with rings of holes for spacing round work such as gear blanks.

Draw-in Chuck.—Has spring or hinged jaws actuated from the rear of the spindle.

Driver.—Rotates shafts, etc., set between centres.

Faceplate.—Put on spindle nose, and holds articles by clamps or dogs.

Feed Shaft.—Lies along the bed, and actuates the saddle and cross-slide feeds.

Follow Rest.—Attached to the rear of the saddle, and steadies a shaft against the cutting pressure.

Fork Centre.—Has a point to centre the wood being turned, and two prongs to rotate it.

Form Tool.—Has a contour corresponding to the one desired to be turned, hence will finish thousands of pieces uniformly.

Hand Rest.—Employed in wood turning and light metal turning to steady hand tools.

Knurling Tool.—Holder with hard-steel rollers cut with pattern which impresses the work.

Mandrel or Arbor.—Centres and drives an object by its bore. Is either solid, or adjustable to fit various sizes.

Pilot.—Guides a tool or tool bar centrally; the pilot slides through a bushing in the spindle or a hole in the work-piece.

Quick Withdraw.—Jerks a cross-slide back instantaneously with a quick-pitch screw to withdraw a screw-cutting tool at the termination of the traverse.

Stops.—Solid abutments which determine travel of tools.

Taper Attachment.—Fitted to the back of a saddle; moves the cross slide to turn tapers.

Turret.—The same as a capstan, which feeds through an intermediary slide attached to the bed, whereas a turret moves direct thereon.

Wire-feed or Bar-feed.—Hand or automatic mechanism which feeds and grips work intermittently in the lathe spindle, as units are machined and cut off.

Great strides have been made in the production of cast iron during the past thirty years. Where 5 tons per sq. in. ultimate tensile stress was considered to be an average for cast iron, iron founders are now producing alloy cast irons with an ultimate tensile stress of 25 tons per sq. in.

In 1921 the Institute of British Foundrymen was granted a Royal Charter. From this organisation developed the British Cast Iron Research Association, and they in turn developed and patented the balanced blast cupola.

Other modern foundry developments are machine moulding, mass production, centrifugal casting, and the mechanisation of foundries. There are also the production of high-duty irons, such as Lanz-Perlitz iron and Thyssen-Emmel iron. Rotary and oil-fired furnaces are now being used for the production of cast iron. These are ideally suited for alloy cast iron, and their use is becoming general in modern foundries.

Raw Materials.—There are four types of iron ore that are used for smelting down into pig iron, namely, magnetite, red hæmatite, brown hæmatite, and spathic iron ore.

Magnetite (Fe_3O_4) is mined in Sweden, and is magnetic. This ore is very pure and often contains between 60 per cent. and 70 per cent. iron. Red hæmatite is found in Cumberland, Spain, Germany, Canada, and U.S.A., and contains 50 to 60 per cent. iron.

Brown hæmatite occurs in Lincolnshire, Northamptonshire, Spain, Germany, France, and America, and contains 30 to 45 per cent. iron.

Spathic iron ($FeCO_3$) is iron carbonate, and is mined in Northamptonshire, South Wales, Staffordshire, Yorkshire, and Scotland. Other sources are Hungary, Germany, and Russia. Iron carbonates contain only 30 per cent. pure iron.

The Blast Furnace.—Iron ore is converted to pig iron by the blast furnace. As shown in Fig. 1, the blast furnace is a cylindrical shaft furnace increasing gradually in diameter downwards from the top to a maximum diameter some distance above the tuyeres. From there the diameter decreases to the bottom.

The height of a modern blast furnace is between 90 and 100 ft. The hearth or crucible extends some 10 ft. from the bottom, and the bosh extends some 12 ft. above the hearth. The stack up to the stock line is about 70

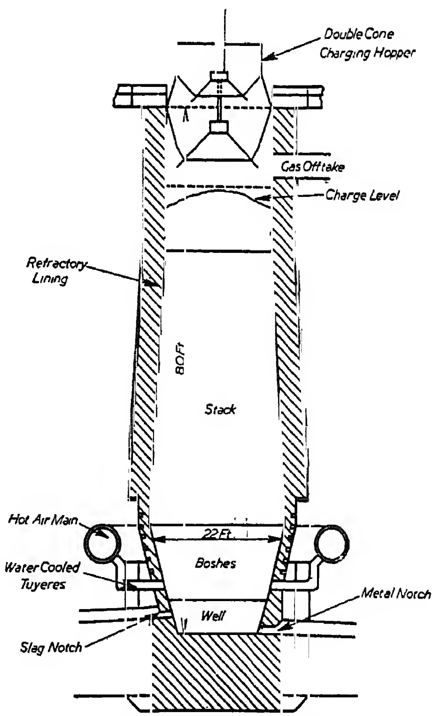


Fig. 1.—Elevation of a blast furnace.

ft. The furnace is lined with refractory material and encased in a heavy steel shell.

The charge consists of ore, fuel, and flux, and is dropped through the double bell hopper at the top of the stack. This arrangement is to enable the furnace to be charged without allowing gases to escape into the atmosphere. The gases are drawn off from the top of the furnace and burned in Cowper stoves. These Cowper stoves are then used to preheat the air blown through the tuyeres. Cowper stoves consist of tall chambers divided into a gas flue and a compartment containing honeycombed refractory brickwork, known as chequer work.

Blast-furnace gas and air are allowed to burn in the flue and pass through the chequers. The brickwork comprising the chequers becomes exceedingly hot and retains heat. After about one hour, gas and air are shut off and the air on its way to the tuyeres is passed through the stove. This preheats the air to about 600° C. By using a number of these stoves, a constant supply of hot air is obtained at the tuyeres.

A Cowper stove is shown in Fig. 2.

The essential reactions in the blast furnace are: the reduction of the ore to sponge iron, which approaches completion about 30 ft. above the tuyeres, and the impregnation of the sponge iron with carbon, and then its melting in the melting zone.

The molten iron is then tapped off from the metal notch and the slag from the slag notch. The slag, which is usually high in phosphorus, is allowed to cool and then crushed and sold as a fertiliser (basic slag).

There are two methods of casting the pig iron—the sand-cast iron and the machine-cast iron.

In the sand-cast process the metal is allowed to run from the furnace on to a sand bed. This consists of a number of channels in the sand, from which smaller channels branch off. The former are known as sows and the latter as pigs—hence the name pig iron. When still red hot the pigs are broken off, and when cool removed, ready for transport.

In the other method, the metal is poured direct into a pig-casting machine. This machine consists of a number of iron moulds on an endless belt, into which the metal is poured.

Grading of Pig Irons.—The varying quality of pig iron from white to grey is caused by the condition of the carbon, which occurs free as graphite, or is combined as iron carbide and is called cementite.

In most irons the carbon occurs in both states. When the carbon is mostly free, the pig iron shows a fracture which is dark grey or nearly black.

When the carbon is all combined, the fracture is silvery white. Iron which is partly grey and partly white is known as mottled iron.

The amount of free carbon existing in the pig iron depends mainly on the silicon content. The more silicon in an iron, the more grey, soft, and weak the iron will be.

This variation from white iron to grey iron in various types of pig is expressed in practice by a series of numbers from 1 to 4 and then mottled and white.

Fracture of a pig iron is a general guide to composition; but it is an uncertain one, for irons of the same kind with apparently the same fracture have frequently very different compositions.

Also the system of numbering varies from one district to another. The only accurate way, therefore, of determining the composition of an iron is by chemical analysis.

Iron and Steel Scrap.—Iron scrap can be divided into two classes: domestic scrap and purchased scrap.

Domestic scrap consists of risers, rejected castings, pigged iron, etc., all of which are of known composition.

With purchased scrap this is not so, and mixed scrap should be avoided. The foundryman should, if possible, obtain scrap representing the same class of work. By doing this he minimises the variations in composition.

Malleable scrap is of fairly constant analysis, with silicon about 75 per cent., phosphorus under 0·2 per cent., and carbon 2 per cent. or above.

Steel scrap intelligently used is a valuable component in cast-iron foundry mixtures. Additions of steel scrap vary from 10 to 90 per cent. of the charge.

Steel lowers the silicon content of the mixture and tends to lower the carbon content. Care must be taken to see that alloy steels are not used in mistake for carbon steels.

Coke.—Coke is the most important foundry fuel. The greatest percentage of foundry coke used to-day is made by the by-product process. In the production of coke, bituminous coal of a suitable grade is heated in retorts without air. The volatile matter, gases, various light oils, ammonia compounds, tar, moisture, and other compounds are driven off. The coke remaining in the retorts is dumped out and quenched with water.

The old beehive method of producing coke has been largely discontinued, because of the wastefulness of this method.

In this method, the coal is placed in domed chambers and coked with a limited admission of air. The process involves losses in heat and valuable volatile products which are recovered in the by-product process.

Coke is a porous material made up of a large number of irregular cells, joined together with walls impervious to gases. Because of its porosity and its large surface exposure, it burns readily under forced draught. Porosity depends on the number and size of the cells. Koppers states that a good foundry coke must have a porosity of 40 per cent.

Good foundry coke must not break easily when handled, and must support the charges during cupola melting.

Coke must, therefore, resist compression, shock, and abrasion.

American foundrymen use a shatter test for finding the resistance of their coke to breakage or handling.

Fifty pounds of material which will not pass through a 2-in. square mesh sieve is placed in a box, and from there dropped four times on to a steel or iron plate. All pieces are returned to the box each time. After the fourth drop the coke is screened with 2-in., 1½-in., 1-in., and ½-in. sieves. Portions are weighed, and the percentages remaining on the various screens and that passing the ½-in. screen are calculated.

For a good coke 85 per cent. of the material should stay on the 2-in. screen.

The best size of coke for cupola melting is considered from 4 in. to 6 in. Somewhat larger pieces are desirable for the bed. Small coke increases the required blast pressure.

If different kinds of coke of equal size are burned in small vertical furnaces as shown (Fig. 3), with equal amounts of air, the softer and more reactive type of coke will produce more carbon monoxide and consequently much higher flames.

Volatile matter in coke is determined by heating a sample of coke in a closed platinum crucible for seven minutes at 950° C. No more than 2 per cent. volatile matter is permitted.

The amount of ash in coke should be limited to 12 per cent., and fixed carbon in the coke should not be less than 86 per cent. Sulphur content should not be more than 1 per cent.

Foundry Fluxes.—The use of a flux in the smelting of cast iron is to help to get rid of impurities. The impurities to be got rid of are the ash from the burnt coke, sand that is charged with foundry

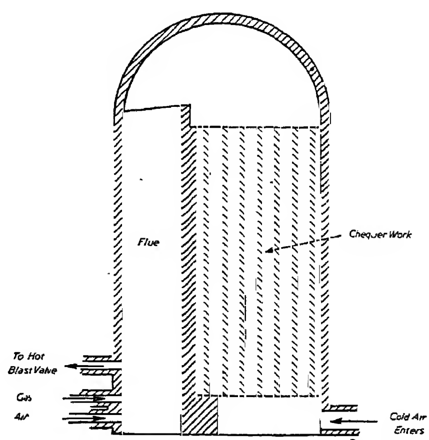


Fig. 2.—Section through a Cowper stove.

scrap, and the rust which is found on an old scrap. These impurities are rather refractory, and the object of a flux is to combine with them and produce a liquid slag which will flow freely.

The most widely used flux for cast iron is limestone or calcium carbonate ($CaCO_3$). Limestone should be of fairly good grade, low in silica and iron, and rich in calcium carbonate.

Silica (SiO_2) usually forms the bulk of the dirt to be fluxed off; this is what happens: Calcium carbonate is charged into the furnace and, due to the action of heat, forms lime:

$$CaCO_3 = CaO \text{ (lime)} + CO_2 \text{ (carbon dioxide)}.$$

This lime then reacts, forming calcium silicates:

$$CaO + SiO_2 = CaSiO_3 \text{ (calcium silicate)}.$$

Sodium carbonate is also a flux that is used rather extensively, and it can be added in conjunction with limestone in the cupola. Sodium carbonate, commonly known as soda ash, can also be added to the ladle for desulphurising and cleaning the metal. Reductions of 50 per cent. in sulphur content of cast iron containing from 0·10 per cent. to 0·15 per cent. sulphur can be obtained by adding 1 per cent. of sodium carbonate. This is placed in the bottom of the ladle, and the metal, as hot as possible, is tapped on to it. A vigorous action takes place, sodium sulphide being formed, with the evolution of carbon dioxide. The mechanical agitation also effects a refinement in the graphite size of the iron, and removes some of the gases and non-metallic inclusions. After about five minutes the vigour of reaction subsides and a soda slag collects on the metal. In order to facilitate the removal of the very fluid slag, ground limestone of about three-quarters the weight of the sodium carbonate is used. This thickens up the slag, and it can then be readily removed.

Fluorspar (calcium fluoride) is sometimes used as a flux. This produces very fluid slags.

Intelligent use of fluxes is an essential factor in cupola operation. Too much flux will result in the lining being acted upon. This applies particularly to sodium carbonate.

Crucible Furnaces.—The crucible furnace is not very often used for melting cast iron, but in some cases, where only a small amount of metal of a definite chemical composition is required, this type of furnace is ideal. The reason for this is that when melting cast iron in a crucible furnace there are practically no melting losses. A slight loss of carbon, silicon, and manganese does occur, but rarely exceeds 3 per cent. of the original content.

There are two types of crucible furnace—the pit type and the tilting type. In the pit type the crucible must be lifted out from the furnace for pouring the metal, but in the tilting type the whole furnace tilts, and the metal is poured from the crucible into a ladle without disturbing the crucible.

The pit type of frunace is usually fired by coke, oil, or gas. It consists of a refractory lined chamber, which is usually sunk into the ground and large enough to take a crucible of the size required. Crucibles vary in size up to 300 lb. capacity, the usual size being 80 or 100 lb.

The crucible is placed on a refractory stool and, in the case of coke, fuel is packed round it.

Air for the combustion of the furnace is supplied by a low-pressure fan or by natural draught.

In case of oil- and gas-fired furnaces of the pit type, the fuel is fed through a burner and mixes with the air.

The tilting furnace may also be fired by coke, gas, or oil. In the coke type, low-pressure air is supplied to a wind belt surrounding the furnace. The air then passes from the wind belt into an enclosed ash pan, and from there up through the fire bars. The crucible may have a capacity up to 700 lb. when oil or gas is fired, and 500 lb. when coke is fired. For oil and gas firing the most popular size of crucible is 400 lb., and for coke firing 350 lb.

With the tilting furnace a hinged preheater section is provided, containing a muffle ring. This preheater section consists of a cylindrical steel shell lined with firebrick. When in position the hot gases from the furnace pass through the pre-

heater and preheat the metal in the muffle ring. When the crucible is ready for pouring, the preheater is swung aside.

The operation of crucible furnaces is fairly straightforward. Melting losses are very small, but to keep these to a minimum, melting should be as rapid as possible.

With coke firing, and using a 350-lb. crucible, cast iron should be ready for pouring in 2 to 2½ hours.

The fuel consumption on all types of crucible furnace is rather high. With coke on single melts, the weight of coke burned may be almost equal to the weight of metal melted. This figure reduces to a coke consumption of 40 per cent. of the weight of the metal melted. A fuel consumption of 30 per cent. of weight of metal melted is considered quite good for oil or gas.

The Air Furnace.—This type of furnace has advantages which suit it for certain classes of work. It is used for melting metal for chilled rolls, and is also used for the manufacture of blackheart malleable cast iron.

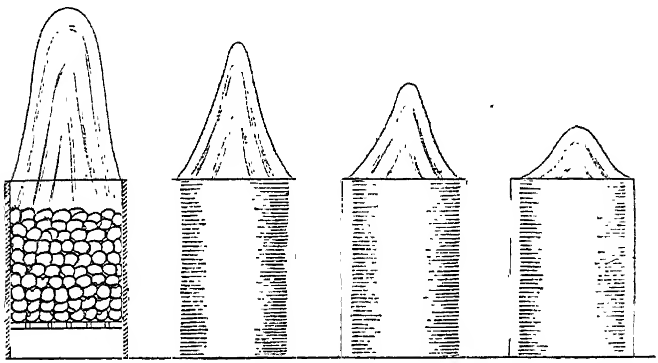


Fig. 3.—Formation of carbon monoxide flames using different cokes under same air pressure.

An air furnace is a reverbatory furnace, and consists of a fire grate, a hearth, and a chimney stack.

One advantage of this type of furnace is that when the charge is molten it can be held in that state, and samples can be taken for examination.

The most usual method of firing the air furnace is by using lump coal, but furnaces are in existence fired with pulverised fuel, or oil.

The designs of air furnaces vary, but the principle on which they work is the same. The flame from the firebox is deflected downwards by an arch on to the charge, which melts and collects in the hearth.

Melting losses with this type of furnace depend on the atmosphere maintained in the furnace. The loss of silicon may be as high as 25 per cent. Also a loss of carbon up to 10 per cent. may be experienced.

The fuel consumption for the air furnace is in the ratio of 2 of metal to 1 of coal.

Rotary and Rocking Furnaces.—The advantage of this type of melting unit is that the metal is melted out of direct contact with the fuel. This is a very important consideration when low-carbon irons are being produced. In this type of furnace the melt can be held at a definite temperature while samples are taken and tested, or it can be superheated to any desired pouring temperature.

The furnace body consists of a horizontal steel shell lined with a refractory. Its shape is cylindrical, tapering at each end as shown, and it is mounted on four rollers, which enables the furnace to be tilted. During the melting operation, suitable electric gear oscillates the furnace backwards and forwards, and so gives a rocking motion to the molten metal.

The rotary furnace may be fired by oil, gas, or powdered coal. The fuel enters at one end of the furnace, and the tapered portion at that end acts as a combustion chamber whilst the other end acts as an outlet for the exhaust gases, which pass down and along the flues to the chimney stack.

The molten metal lies in the main cylindrical portion of the furnace, and is tapped by simply rotating the furnace until the metal runs from the tapping spout which is provided on the casing.

The charging of the furnace is effected from the exhaust end. There is a movable exhaust box, which, when the furnace is being charged, is moved to one side. A charging machine may be used to charge the furnace, or it may be charged by hand.

These furnaces may be obtained with a capacity varying from 10 cwts. to 15 tons, and, not considering the first melt, will produce molten metal $2\frac{1}{4}$ hours after charging.

The fuel consumption of the rotary furnace is economical. With oil firing the fuel consumed is generally 18 to 20 per cent. of the weight of the metal melted.

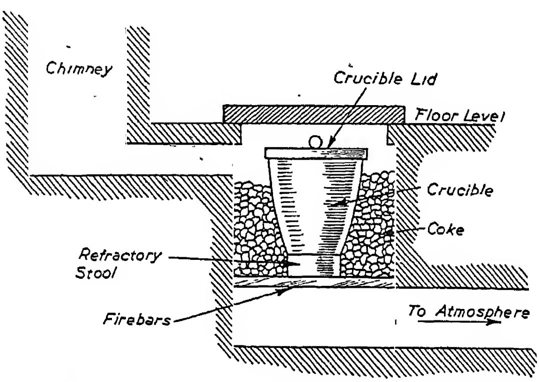


Fig. 4.—Section through pit-type crucible furnace with natural draught.

Melting losses with this type of furnace are lower than those of a cupola, and there is no carbon pick-up.

Electric Furnaces.—Electric-melting units may be divided into three classes, namely, induction furnaces, resister furnaces, and arc furnaces. All these types of furnaces are used in this country mainly for melting steel. Cast iron is very seldom melted in the electric furnace, because of the high melting costs. However, on the Continent and in America, where electricity is very cheap, there are melting furnaces which are used solely for melting cast iron.

The electric furnace has one great advantage over the cupola, for the charge can contain a substantial amount of cast-iron borings, turnings, and sheet clippings. These cannot be used in the cupola, and in this respect the electric furnace competes successfully with the cupola.

The Cupola.—The cupola is the melting unit that is most commonly used in the foundry for the production of cast iron. It is the most popular because it is easy to operate, highly efficient, and has exceptionally low melting costs.

The cupola is a vertical steel shell, lined with refractory material and having a hinged bottom plate. When prepared for use, the hinged bottom plate is wedged in position and a sand bed is made up on it. This sand bed is made up through a hole situated at the bottom of the shell, and known as the fettling hole. When the cupola is in use, this hole is made up with sand and closed with a steel plate.

About 2 to 3 ft. above the bottom of the cupola there are a number of inlet

holes or tuyeres through which an air blast is supplied. These tuyeres are covered by a wind belt which surrounds the cupola.

The Charging Hole.—About 10 ft. above the bottom of the cupola there is another hole in the shell and lining, and this is the charging hole. Through this hole all metal and coke are fed to the furnace. A tapping hole is provided about 4 in. above the bottom of the shell, and a slag hole is provided about 6 in. below the bottom of the tuyeres.

The melting rate of a cupola depends largely upon its cross-sectional area, and is between 0·75 and 1 ton per sq. ft. of section per hour.

The refractory lining inside the steel shell of the cupola must be sufficiently thick to prevent the shell melting. The minimum thickness is about 6 in., and can be up to 12 in.

There are two methods of lining a cupola—there is the straight-shaft cupola and the boshed cupola. In the straight-shaft cupola the internal diameter of the lining remains constant from the bottom up to the charge door. In the boshed type the internal diameter of the lining is increased gradually up to the position of the melting zone, and is then continued parallel up to the charge door.

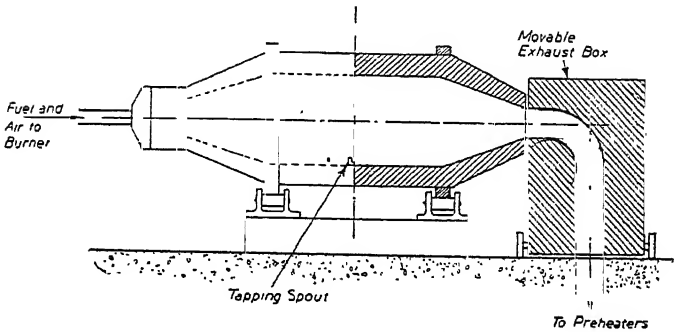


Fig. 5.—A rotary furnace.

The Charge Door.—For efficient working, the charge door in a cupola should be at the highest practical point; the height of the stack above this being only that necessary to provide draught for lighting up. The distance, therefore, between the main tuyeres and the charging hole should be from five to six times the internal diameter of the cupola for a small cupola and four times this diameter for a large cupola.

The height of the tuyeres from the bottom governs the depth of the cupola well. This well is where the molten metal is stored. A reasonable depth for the well is 2 to 3 ft., depending on the size of the cupola.

The tuyere area for a cupola is between 12 per cent. and 20 per cent. of the cross-sectional area of the cupola at the melting zone. The tuyeres are usually reactangle in shape and placed evenly round the circumference of the lining. Usually cupolas up to 30-in. diameter have four tuyeres, and those above this diameter have four to six tuyeres.

The amount of air required to pass through the tuyeres when the cupola is in operation depends on the rate of combustion of the coke. Assuming the coke combustion to be 150 lb. per hour for each square foot of section, the required blast volume would be 21,000 cu. ft. of air per square foot of cupola cross section.

Cupola Preparation.—The melting zone of the cupola is denoted by the fusion or scoring of the cupola lining a little above the tuyeres. Scoring above the tuyeres suggests the highest temperature at the wall. The scored area indicates certain things about the bed height, the balance of coke charges, and the air supply. A clearly defined melting zone should be cut in for a height of 4 in.

to 8 in. on a nearly even level. Absence of a scored melting zone generally means improper coke ratio between charges.

It may indicate an excessively high bed. If the melting zone line is uneven horizontally and the scoring is irregular, then the air flow is probably not uniform, and the possible causes should be investigated and faults remedied.

When preparing the cupola for melting, all slag and iron are first chipped from the walls, and the places ravaged by the heat are repaired with ganister to make the internal diameter the correct size. To do this the walls should be well moistened, and the ganister then pressed on hard and smoothed on level on the outside. When this has been done the drop-bottom doors of the cupola are closed in position, and the sand bottom is made up on them. The sand used for this bed should be well-riddled floor sand, containing about 5 per cent. moisture, and should be rammed fairly hard to a depth of about 4 in. If the sand is too wet and is rammed too hard, the iron will boil and parts of the bottom will come up. A wet bottom also causes dull iron on the first tap. Next, the tap hole is made; this being done by putting a wooden peg of the correct diameter on the cupola bottom and ramming ganister round it. The plug is then withdrawn and leaves a hole. The parallel portion should not be longer than $1\frac{1}{2}$ in.

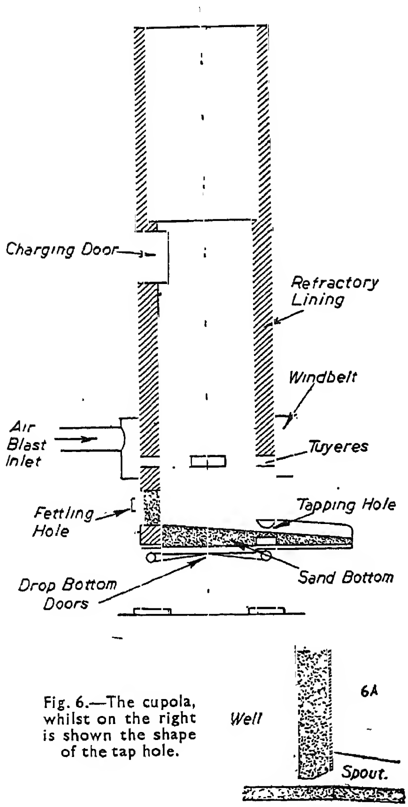


Fig. 6.—The cupola, whilst on the right is shown the shape of the tap hole.

Coke Bed.—Next comes the laying of the coke bed. Pieces of wood for ignition of the bed should be laid criss-cross on the bottom to form a lattice work through which air can pass freely, but so arranged that the subsequent wood and coke cannot cut the bottom sand. A number of larger pieces of wood are then placed upright around the sides to protect the recent patchings. After then adding the desired amount of coke, a light is applied at the bottom, and all the apertures in the cupola are left open to provide a draught. More coke is now put on, this time through the charging hole, until the bed of coke is the desired height. The height of the bed varies between 24 in. and 48 in., but a safe height for the coke bed is 32 in. When this bed is well ignited, the fettling hole is made up by ramming sand to a depth of 32 in. on to the coke. The breast plate is then put on over the sand.

Charging the Cupola.—The first metal charge can now be put on, followed by a coke charge. This is done and the blast is now turned on. Alternate charges of metal and coke are now placed in the cupola until the stack is filled up to the charging hole. With each ton of metal about 40 lb. of limestone is charged.

The ratio of coke to metal depends on the efficiency of the cupola, but for a good cupola 1 lb. of coke is added to every 10 lb. of metal.

The tapping hole should also be made up before putting on the blast. This is done with damp clay.

In about ten minutes the metal should begin to trickle past the tuyeres. The metal collects in the well of the furnace, filling in the spaces between the coke lumps. As soon as sufficient metal has collected in the well, the tap hole is broken open and the molten metal is run out into a ladle. When sufficient metal has been tapped, the tap hole is made up again, until more metal has collected in the well of the furnace.

As the metal melts, the charges of coke and metal sink farther down the shaft, and more charges have to be put on.

Moulding Methods.—Methods of moulding and pattern construction are decided before the pattern-maker makes any move. He forms a mental image of the pattern from the drawing and decides the best way to mould it. If it is complicated he may have to consult the moulder.

There are many cases where a full-size drawing must be made, generally involving more than one view of the required pattern. This is necessary because patterns are scarcely ever cut from a single piece of wood, but have to be built up even when quite small, a task that would often not be practicable without full-size views from which measurements could be taken.

The pattern-maker does not draw on paper, as is done in the office, but direct on drawing boards, some of which have to be very large to suit full-size work. They vary in proportions, and a stock of them is kept. These boards consist of pieces held edge to edge by battens screwed to the back. A board is not considered unsuitable if it is not quite large enough to include one or more extending portions of a drawing, as a few inches can be added temporarily to any part of the edge of a board. Occasionally a special board may be made where circumstances make it worth while.

The Drawing.—The board rests on trestles, and powdered chalk is usually rubbed into its surface. Old drawings are sometimes obliterated in this way, but eventually the surface has to be cleared with a smoothing plane. This is because, where great accuracy is required, lines are scribed or cut into the surface instead of being drawn with pencil.

Allowance for shrinkage of metal in cooling is made on a full-size drawing, but seldom allowances for machining. The pattern-maker generally works with a contraction rule which, being a little longer than standard, gives automatically the allowance for shrinkage. This, however, is only approximate, and some men prefer to estimate shrinkage.

Small castings may come out slightly larger than the pattern, owing to the practice of rapping the latter to loosen it in the mould prior to withdrawal. The same practice is adopted with all patterns, but small moulds are most affected by it. A plate of large area will come out in the casting a little thicker, owing to pressure of metal between upper and lower sand when pouring. Different kinds of metal shrink differently, and also different grades of nominally similar metal. Great exactness in measurements of castings cannot therefore be determined unless in work that is constantly being repeated.

Parts shown in section are shaded with diagonal lines, the same as in office drawings, to make the drawing as clear as possible at a glance. Prints are not drawn unless for convenience in getting the size of core-boxes.

Sand Moulds.—A handful of foundry sand can be taken and squeezed and it will retain the shape into which it is squeezed. The damp condition in which it is kept assists it in this respect, for if absolutely dry it would be useless for making moulds. In addition, it has a natural cohesive quality which distinguishes it from other kinds of sand. It is this characteristic which enables a mould to keep its shape after the pattern is withdrawn.

The mould requires rather careful handling, and the pattern must be designed for easy withdrawal. Thus, other things being equal, a pattern which is deep in one direction and shallow in another would be moulded with the broad surface down and the narrow faces at the sides, so that there will be the minimum amount of lift from the mould. The reason for this is that a slight amount of taper, or draught, is usual for making an easy lift without tearing up the sand. On a con-

siderable depth, this taper would be cumulative and might be objectionable on the casting.

It is obvious that projections on the sides of a pattern with sand above them would not leave the mould; nor could hollow interiors almost surrounded by metal be formed from a pattern of similar shape. Moreover, even when direct withdrawal appears possible, there are many cases where the sand would not remain behind but would lift with the pattern. Additionally, the lifting of a body of sand from the upper surface of a pattern is a delicate operation if there are any projecting parts in the top. Such parts must be shallow, and need much more taper than corresponding parts in the bottom of the mould. Alternatively, they must be loose so that they will either lift with the sand or can be used by the moulder for mending up broken sand after the pattern is out.

Wood as a Material for Patterns.—Wood is a porous material which shrinks or swells as the amount of moisture in it varies.

Foundry Moulding-boxes.—Except in extremely large work the pattern does not go into the loose sand on the foundry floor. The sand is enclosed in boxes, or flasks, as they are sometimes called. They are usually of iron, without botton or top. All the larger boxes have bars to keep the sand from falling out in a mass, for the boxes have to be lifted and turned over in the process of making the mould. In the simplest work, and in fact in most work, a mould requires two boxes, and this is the case when the top one provides only a flat surface of sand for covering the mould left by the pattern. In more complex work three boxes are often necessary.

If we take a plain cylindrical body, it is evident that it can be moulded in two ways—on end or on its side. If it were very long in proportion to its diameter it would be best moulded on its side, but under certain circumstances it would be better to mould it on end. Two moulding-boxes would be used in either case but, with the pattern on its side, half the mould would come in the upper box. It would be centrally divided, the pattern being made in halves unless very small. Sand would easily lift off the semicircular part, but the ends would not be so easy; they would need some convexity. Moulding on the side, therefore, would seldom be adopted for a plain cylindrical body. If moulded on end a little taper would be desirable, but, unless it was made obvious in some way, the moulder might be in doubt which way it was intended to mould, for the moulder has not the means of making such accurate measurements as are possible in the pattern shop, and often his eye is not so well trained as the pattern-maker's. Therefore if the body is only a small one, and its length short, it could be made perfectly parallel without giving much trouble in withdrawal.

There are cases where a pattern-maker decides on one way of moulding a pattern and the moulder chooses another, either because he does not see the pattern-maker's intention or because he thinks a way of his own is better. This is possible with some patterns, but not with many.

If the body has a flange or collar at one end, it would be an additional reason for moulding it on end, provided that its length is not excessive, the collar, of course, being at the top. It would be given a slight taper lengthwise, and the ends would be flat. This is a case where the moulder could be in no doubt about which way the taper should be. But if it had a circular collar at both ends, the conditions are altered. To put it into the sand on end would mean that it could not be lifted out except by allowing the lower collar to tear and destroy the mould. Its shape, therefore, decides that it must mould on its side, the pattern being made in halves, dowelled together to keep them in correct relation with each other, and the sides of the collars tapered.

In some castings which have to be machined, any extra trouble in moulding is sometimes avoided by cutting out recessed parts in the machine shop, provided that it does not involve the removal of much metal.

In all patterns the vertical parts in the mould should be tapered as much as they can be without detriment to the casting. Some parts can be given a great deal of taper; others very little. Others again have a shape which gives them a large amount of natural taper.

There are two other ways in which the upper part can be dealt with. One is to make the foot in a single piece, tapering in one direction, but have the upper boss and rib loose. The moulder then makes a sand joint which allows upper

sand with boss and rib to be lifted away from the web and inner face of the foot.

Another way is to make the pattern with only the rib loose and let the moulder make his joint, the foot and the part of the boss below this line being tapered for lifting out of the bottom part of the mould.

The moulder can make sand joints of any contour between upper and lower boxes by sprinkling a layer of parting sand on the lower contour, which he has shaped so that the upper part, after being formed on it, can be lifted away. The parting sand is a very dry variety which prevents adhesion in the joint. Moulder's joints, in fact, are not necessarily flat to correspond with the moulding-box joints. Portions of sand in one box may bulge into space in the other. The making of such joints, of course, gives the moulder trouble, and the pattern should be designed to simplify it as far as possible.

The Building-up of Patterns.—Wood is liable to shrink and curve across the grain and can easily be split. But in line with the grain its shrinkage is negligible and it cannot split, though if slender enough it can be bent and snapped. The bending, or lengthwise curvature, may become permanent if the wood is under prolonged stress. But, with a few exceptions, a piece of wood does not require stiffening lengthwise.

It is the cross grain that needs strengthening, and this is done by crossing the grain, by framing, and by cutting the pieces so that the grain runs in the direction of their greatest dimension. In a narrow strip the cross grain is too little to make any difference, but as width increases so does the need for stiffening the cross grain.

Castings, except very small ones, are usually a kind of framework or shell of metal which is nowhere very thick compared with the size of the casting. Patterns are built up on the same principle, though the thickness of metal in the casting is not always arrived at by making the wood of the pattern a similar thickness. In very many cases the interior of a casting is taken out by putting cores in the mould, and the pattern has only the outside appearance of the casting, and not exactly the same at that.

Screws in Patterns.—Joints of this kind are nearly always screwed together. Pattern-makers use screws where most other woodworkers would use nails. The reason for this is that patterns in stock are often altered in preference to making entirely new ones. Sometimes new ones wanted in pairs, right and left hand, require alteration from one hand to the other. If such patterns are small and a large number of castings is wanted, it pays to make two patterns.

With patterns being constantly turned out in a shop, a great deal of room is needed for storing them after they leave the foundry. Some are never likely to be wanted again, and if they are large it is often best to take them apart and use the material for other work. If they are screwed together this can easily be done, but nailed work demands violent treatment with more or less damage to the wood. Fine wire nails, however, are used extensively for attaching small parts, as these can generally be prised off with a chisel. But if it is probable that they will have to be removed and perhaps replaced, screws would be used. Glue is used comparatively little except for building up thicknesses and widths, where such parts can be regarded as solid wood.

The joints adopted in pattern construction are simpler than in most other woodwork. The majority are plain butt joints, screwed, and where this is not possible their form still remains simple as far as is consistent with adequate strength and permanence of form. Dovetail joints, for instance, are scarcely ever employed; in most shops they are never used. An objection to them is that they might tear up sand if any slight overlap developed.

Next to the butt joint in simplicity is the rebated, or trenched, joint. This is used chiefly for patterns that are boxed up on all sides. If the joints in such patterns were not rebated, a blow against the outer face might knock an end inward sufficiently to cause an overlap which would tear up sand in withdrawal from the mould. It would be troublesome to correct the displacement. Another reason is that the part in which the rebate is cut must be a definite thickness to suit the width or length of the piece that enters the rebate. This can easily be marked with a gauge from a true outside surface, and the work of planing the entire inside surface down to a thickness avoided.

Halved Joints.—The mortise and tenon joint, so common in other branches of woodwork, is not used in patterns. The half-lap, or halved joint, takes its

place. It is made by cutting away half the thickness of each piece so that they join in the same plane. The parts have to be screwed together. It is less trouble to make, and is more suitable for the considerable widths which often have to be jointed. Moreover, it is a case where appearance does not count. Such joints may be at any angle, but the most usual is at right-angles.

Cores.—Only very simple moulds indeed can be made without cores. A core is a body of sand which has been formed to shape in a core-box and afterwards baked in an oven to dry and harden it. It is stronger than the other sand parts of a mould, but will not stand very rough handling. It is placed in position in the mould after the pattern has been withdrawn, and a mould is thus produced which would be impossible with the pattern alone.

With very few exceptions, prints must be put on the pattern to ensure the correct placing of cores. These prints are made to suit the shape of the core and, as they stand out on the pattern, they leave impressions in the mould into which the cores fit. This not only adjusts a core for position but keeps it there, for a light core not in a print impression might be displaced when the metal enters the mould.

Prints and cores are often used in cases where a person not accustomed to the work might think the pattern would mould if made like the casting. Sometimes it would, but the use of cores is so standardised that it is often less trouble to put a print on the pattern than to cut a hole. But in other cases the hole, though tapered and smooth, would come out choked with sand that ought to have remained behind. In other cases, again, a stronger pattern is possible when an opening is cored.

Round, or cylindrical, cores are by far the commonest in ordinary work. In all ordinary diameters such cores are kept in stock in the foundry and can easily be cut to any length required. They are made in standard iron boxes, so that the pattern-maker has only to put prints on the pattern and the foundry provides the cores. In other shapes than round the pattern-maker has to make core-boxes to go with the pattern.

Core-boxes.—When there is no core-box in a foundry for making the round core required, the pattern-maker has to make a box. This is done by dowelling two halves of wood together, the correct length of the core, marking a circle on each end with compasses, and gouging and planing the semicircle out in each half.

If a top print with a good deal of taper is on the pattern, the box is generally made to suit this taper. Otherwise the moulder rasps the end of the core down to fit the taper.

In the case of rather large boxes, especially if only one or two cores are wanted, it saves time in the pattern shop if only one-half of the box is made, with closed ends. The moulder, or rather the core-maker, then makes two half cores and cements them together.

Chambered Boxes.—Boxes for cores of cylindrical shape are sometimes complicated by not being of uniform diameter throughout. A chambered hole through a casting is sometimes wanted; that is, a hole of a certain diameter extends for a short distance in from each end and then the diameter is increased in the middle part. This is generally done to avoid boring a long hole in the machine shop, and also to reduce friction if the bore carries a spindle or shaft.

The box can only have the chambered part marked on the joint faces and a plane cannot be used. Instead, the cutting must be done entirely with an outside or firmer gouge. There is the possibility of making middle part and ends separately, and nailing them together after, but, as the internal angles are always rounded, cutting the entire length out of the solid is usually preferred.

A template of thin wood is made for testing the chambered part as the work with the gouge proceeds.

The general principle in making core boxes is to have them as open as possible. Thus a rectangular box for a core measuring, say, 6 in. by 10 in. cross section, would have its sides 6 in. wide, with open top and bottom the 10-in. way. This economises material and in some cases facilitates the making of the core. In other cases it may provide more trouble in levelling off a broad surface.

When fluids flow they do so under the influence of gravity or as a result of an applied force or pressure, and as with solids they encounter frictional resistance to their flow. One method of finding the velocity of a liquid flowing under open-channel conditions is by means of the Pitot tube, which consists of a tube having its lower end curved through a right angle. It is inserted into the stream or liquid channel bent end downwards, with the opening of this end facing the direction of the flow of the stream. By noting the height of the liquid in the tube, its velocity or rate of flow can be estimated. Another instrument used for the same purpose is the current meter, which is electrically operated, and takes the form of a vaned wheel rotated by the flowing stream or river.

Loss of Head.—When water flows through a pipe the frictional resistance which it experiences increases with the length of the pipe. Hence, the loss of head or pressure is proportional to the length of the pipe through which the water flows.

As the diameter of the pipe increases fluid friction decreases. As the speed of flow of a fluid through a pipe increases the fluid friction also increases, and this increase is nearly proportional to the square of the velocity flow.

Hammerblow.—If a liquid is flowing steadily through a pipe and its flow is suddenly impeded so that the liquid is brought abruptly to rest, a sudden pressure rise will occur giving rise to a pressure wave, which will travel along the pipe, giving rise to a noise known as hammerblow.

Vena Contracta.—A stream of liquid issuing from a jet has exactly the same diameter as the orifice. It immediately contracts in diameter after passing through the orifice, until at a small distance from it the stream assumes parallel size. The section of the issuing stream or jet of liquid at which the jet sides first become parallel is known as the *vena contracta*, or the " contracted vein " of fluid. The reason for the formation of this *vena contracta* is that the liquid particles, as they approach the orifice, proceed in paths which converge beyond the orifice, so that the escaping jet or column of liquid must necessarily attain a smaller (and a minimum) diameter a little distance away from the orifice.

The actual degree of contraction of the issuing stream of liquid depends upon the size of the orifice, its shape, and upon the liquid pressure or " head " in the vessel. The ratio between the area of the orifice and the area of the jet of liquid at the *vena contracta* is known as the " coefficient of contraction." This coefficient varies somewhat according to the dimensions and the shape of the orifice. For small orifices with fairly sharp edges it is approximately 0·64.

The coefficient of contraction of an issuing stream of liquid is thus established by the expression :

$$C = \frac{\text{Area of jet at } \textit{vena contracta}}{\text{Area of orifice}}.$$

Usually the *vena contracta* occurs at a distance from an orifice equal to half its diameter, the diameter of the contracted part of the jet to the diameter of the orifice being in the ratio of 5 : 7.

Water particles passing through the orifice undergo a reduction of velocity in so doing, but, having passed through the orifice, the water particles attain a maximum velocity at the *vena contracta.*

Coefficients of Velocity and Discharge.—What is known as the " coefficient of velocity " in respect of issuing streams of liquids from orifices is simply the ratio between the actual jet velocity (at the *vena contracta*) and its theoretically calculated velocity. For sharp-edged orifices this difference between theoretical and actual velocities is barely appreciable. The ratio is of the average order of 0·97 to 0·98.

A similar ratio is that known as the " coefficient of discharge." This is the ratio between the amount of water discharged through an orifice (in unit time) and the theoretical amount which should be so discharged. In consequence of the contraction of the jet after passing through the orifice and to its reduction in velocity, the actual discharge is always considerably less than the theoretical

discharge. This ratio also varies according to the water head or pressure and the type of orifice used. On an average, the "coefficient of discharge" ratio is about 0·6; that is to say, that, in actual practice, only a little more than half the theoretically possible quantity of water is discharged from a tank through an orifice in any given time.

Force Pumps.—Pressure pumps are generally known as "force pumps," for they impart energy to the water and give it an "artificial head." Suction pumps, which raise the water or other liquid by suction, operate usefully only when the height to which the liquid has to be raised is not great. They are essentially "low-lift" pumps. Actually the maximum height to which water can be raised by means of a suction pump is theoretically equal to the height of the water barometer—about 34 ft.—but in practice no suction pump will raise water above a maximum height of from 25 to 30 ft. More usually 25 ft. is the maximum distance which a suction pump will raise water. This deficiency is accounted for by mechanical defects and inaccuracies in the pump system itself, and also by the fact that water, under the influence of a partial vacuum created by suction, exudes its dissolved gases, which consequently lower the degree of vacuum set up by the pump plunger above the water surface and consequently "spoil the suction."

Suction pumps, as a class, are also generically known as "lift pumps," in contradistinction to the pressure or force pumps, in which the liquid is actually impelled by the application of force.

Pumps may be classified into two main types—reciprocating and centrifugal pumps.

A reciprocating pump consists essentially of a simple type of barrel or cylinder in which a piston or plunger is caused to move backwards and forwards by applied power. The motion of the piston or plunger creates alternately a vacuum and a positive pressure in the cylinder, as a result of which the water is raised from a lower to a higher level.

A reciprocating pump is termed "single-acting" when the water acts on one side only of the piston or plunger. In such an instance the water is sucked into the cylinder by the outward stroke of the piston, and subsequently forced out of the cylinder on the inward piston stroke.

It is possible theoretically to calculate the amount (volume) of liquid discharged or delivered up by an ordinary reciprocating plunger pump. This is merely the volume displaced by the plunger at each stroke multiplied by the number of delivery strokes of the plunger per minute or other unit time.

The discharge of a plunger pump may be greater or less than its theoretical discharge. What is known as a pump's "coefficient of discharge" is merely the ratio between the volume of liquid displaced by the plunger per stroke and the actual volume of liquid discharged by the pump per stroke. The difference between these two volumes is often known as the *slip*.

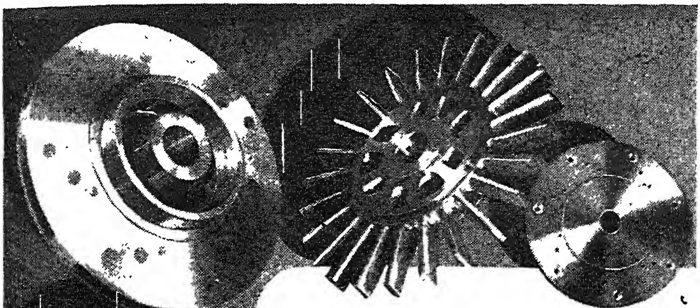
If the actual pump discharge is less than its theoretical discharge, this difference or *slip* is said to be positive. If, on the other hand, the pump discharge is greater than its theoretical amount, the *slip* is said to be negative.

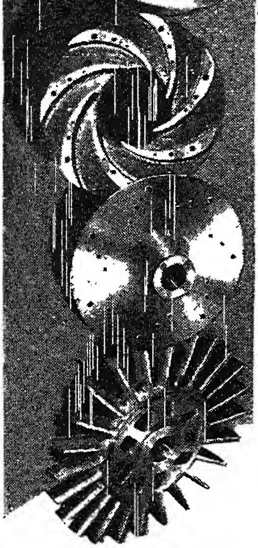
Positive slip is usually the consequence of leakage of liquid past the plunger and valves of the pump. In a good plunger pump, steadily operating under favourable conditions, positive slip should not exceed 5, or at the most 6, per cent.

Negative slip—when the pump discharge is *greater* than its theoretical amount—is due mainly to the fact that, at times, the liquid pressure rises above the delivery pressure and causes a discharge before the end of the suction stroke is reached. This is occasioned by the water in the pump barrel overtaking the outwards-moving plunger, so that a localised increase of pressure is set up. The consequence of these circumstances is that the pump actually delivers up more liquid than its theoretically calculated amount.

Multi-stage Pumps.—This comprises a battery of centrifugal pumps, several impeller wheels being fitted in series, so that the discharge from the first impeller chamber enters directly the second chamber and thence proceeds to a third impeller chamber, and so on until the desired pressure or head of water is obtained.

In a multi-stage impeller pump all the various impellers are generally keyed to the same common shaft, so that each impeller revolves at precisely the same rate as the others of its series.



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The over-all working efficiency of a pump is frequently referred to in terms of its "duty." In the case of a steam-engine-driven pump, the "pump duty" represents the number of foot-pounds of work supplied by the pump for every 1,000,000 British Thermal Units given up to the engine by the boiler.

At one time the term "duty" as applied to pumps was taken to denote the number of foot-pounds of work developed by the pump per bushel of coal burned in the boiler of the operating steam-engine. Obviously in this case boiler efficiency was made part and parcel of the pump's efficiency.

If a pump delivers X lb. of water per second against a pressure or head of Y feet, then:

$$\text{Work performed by pump} = XY \text{ foot-pounds per second.}$$

Now, the number of British Thermal Units supplied to the engine per second is equal to: Weight of steam used per second $\times$ total heat of 1 lb. steam supplied. Hence the "duty" of the pump will be represented by:

$$\frac{XY1{,}000{,}000}{\text{Weight of steam used per second} \times \text{total heat of 1 lb. steam}}.$$

Compressed-air Pumps.—The action of this type of pump follows in consequence of the compressed air acting on the water and forcing it upwards; also by the air acting as a sort of continuous piston and pushing the water upwards in front of it.

At high discharge rates the former action takes place; whilst at low rates of discharge the compressed air appears to act in a piston-like manner, pushing the water upwards in front of it; this action being somewhat intermittent and the pump tending to operate in a definite cycle.

Internal-combustion Pump.—In this type of pump the power or force necessary for the raising of the water is developed by means of exploding a combustible gas mixture in a strong vessel above the water surface, the exploding mixture being in actual contact with the water surface and thereby forcing it along a supply pipe. The chief value of the internal-combustion pump lies in the fact that it entirely dispenses with all reciprocating, revolving, or otherwise mechanically moving parts or components. It has practically no parts to wear out, apart from its necessary gaseous admission and exhaust gear.

Water-wheels and Turbines.—Water-wheels are of two main types—impulse wheels, by means of which water acts by impulse or impact so that the kinetic energy of the water is made to actuate the wheel, and those which are operated mainly by the actual weight of the water. The only practicable type of impulse wheel is the undershot water-wheel. The undershot wheel requires no special fall in the water other than that necessary to give rapid motion to the stream. It acts chiefly by the momentum of the stream, the positive weight of the water being of little importance.

Poncelet Wheel.—This is an undershot wheel having curved blades, and it has a working efficiency of from 55 to 65 per cent.

The Overshot Wheel.—In this type the water impinges upon the upper part of the wheel, and thus it is actuated by the weight of the water falling on it. It is more efficient than the undershot type, requiring much less water to act with. It requires a minimum fall of water rather greater than its own diameter. Overshot wheels are equipped with buckets or water compartments set equally around the periphery of the wheel.

Breast Wheels.—In this type the water, instead of entering the wheel at its upper or lower point, enters it at breast height, i.e. approximately half-way between the upper and lower points. It generally revolves in a very narrow casing. Its efficiency is not high.

Tail Water.—In all types of water-wheel it is essential that adequate arrangements are made for the rapid escape of the tail water or exit water, otherwise eddy currents and back pressures will be set up.

Pressure Turbines.—In the pressure or reaction turbine, the water enters the wheel under pressure. It flows through the vane system. During its

passage the pressure head of the water is converted into "velocity head" or, otherwise, into "energy of motion." Finally, the water leaves the turbine freely and at atmospheric pressure.

Reaction or pressure turbines are of several distinct types. There is the outward-flow turbine, in which the water flows into the turbine at its centre and, after passing through its blades, is discharged at its outer edge. Then there is the inward-flow turbine, in which the above direction of water flow is reversed, the water entering the turbine at its periphery and leaving it at its centre and in a direction exactly parallel to its axis. Finally, what is known as the mixed-flow turbine is a type of reaction turbine in which a combination of inward and axial water flow is made use of, the water flowing into the turbine radially and leaving it by its axis.

The impulse turbines, or "velocity turbines," convert the available head of water into velocity before the water actually impinges upon the turbine runner. The pressure of the water remains constant as it passes through the turbine. In all instances it is equal to atmospheric pressure. Hence, in an impulse or velocity turbine air must always be allowed free access to the vanes. Due to the kinetic energy of the moving water, work is expended on the vanes, thus creating a rotation of the drum or wheel to which they are attached.

Impulse turbines are usually of the radial- or axial-flow type. In the radial-flow turbines of this type, the water flow may be either outwards or inwards. Such turbines appear to have been more extensively used than those of the axial-flow type.

Pascal's Law.—In the case of liquids, applied pressure is not transmitted merely in its original direction of application. The liquid transmits the pressure in *all* directions. This is Pascal's Law of fluid pressures.

Pressure exerted anywhere upon a mass of liquid is transmitted without loss in all directions, and acts with the same force on all equal surfaces and in a direction at right-angles to those surfaces.

Equal Pressures.—Assuming that a piston exerting pressure on a liquid has a cross-sectional area of 4 sq. in., if a weight of 4 lb. is applied to the piston there will be an opposing pressure of 1 lb. in each of, say, four pipes connected to the vessel containing the fluid and each having a cross-sectional area of 1 sq. in.

Conversely, if we apply a pressure of 1 lb. to an area of 1 sq. in., it will produce, by transmission through a liquid over an area of 10 sq. in., a corresponding pressure of 10 lb. This is known as the hydrostatic paradox, which asserts that any force, no matter how small, can be made to raise any weight no matter how large. This is the principle of the hydraulic press, in which a steel vessel is filled completely with water and is equipped with two freely moving watertight pistons or rams of different sizes and strokes.

If the smaller piston has, for example, a cross-sectional area of 5 sq. in., and carries a load of $2\frac{1}{2}$ tons, in this case the downward pressure on the water which is exerted by this piston is equal to $\frac{1}{2}$ ton per sq. in., since the total piston area carries a total load of $2\frac{1}{2}$ tons.

Assuming that the larger piston or ram has a cross-sectional area of 40 sq. in., the water will exert against this piston a force of $\frac{1}{2}$ ton per sq. in., which is equal to 20 tons. Hence, for a downwards pressure of $2\frac{1}{2}$ tons on the smaller piston, a corresponding upwards pressure of 20 tons is exerted on the larger. The stroke of the smaller piston or ram must, of course, be greater than the corresponding stroke of the larger; for water being practically incompressible, the smaller plunger in its descent must displace as much water as the larger vacates in its ascent. Thus, in this example, as the larger piston has eight times the cross-sectional area of the smaller, the downwards movement of the smaller piston must be eight times as great as the upwards movement of the larger. This is known as the Movement Ratio or Velocity Ratio, and the mechanical advantage is likewise 8, ignoring frictional and other losses.

Relative Weights of Liquids.—If two or more liquids of different relative weights are poured into a vessel, the liquids, provided that they are not intermiscible, will dispose themselves according to their specific gravity, the lightest rising to the top and the heaviest sinking to the bottom.

If two liquids of different relative weights are poured into a U-tube or any other type of bent tube, so as to meet at the bottom or middle point of bend, the

liquids will balance each other, each keeping to its own side of the tube. The height which each liquid assumes on its side of the tube will be in inverse proportion to its relative weight, the heavier liquid being the lower.

When a solid body is placed in a liquid it will sink, float, or remain in any place in the fluid in which it was placed. If the solid body is exactly as heavy as the liquid, it will remain in any position in the liquid.

Archimedes' Principle.—When a solid body is plunged into a liquid, the quantity of liquid which it displaces is exactly equal to its own bulk. Thus, by plunging a solid body into a known volume of water and noting the precise upward rise in the volume of liquid, it is possible to measure the bulk or the volume of an irregularly shaped body. Hence, if a body is weighed in air, and then weighed in water (or in any other liquid), it will appear to lose in weight as much as the weight of its equivalent bulk of water, due to the upwards pressure of the water. By weighing bodies in air and in water, their relative weights or specific gravities are determined; the specific gravity of a substance being the ratio of the weight of a given volume of the substance to the weight of the same volume of a standard substance—usually water at a temperature of 0° C. or 15° C.

In the case of a gas, the standard substance is generally dry air or hydrogen. Specific gravity is thus $\frac{W}{V}$

Sprengel Tube.—A Sprengel tube may be used for determining liquid S.G. This comprises a U-tube of glass, one end of which is drawn out to a fine capillary tube, which is filled with the liquid whose S.G. is to be determined by dipping the fine nozzle under the liquid and sucking the wider end of the tube until the liquid completely fills the tube to a scratch mark. The tube is then weighed, emptied, cleaned out and refilled with distilled water, and weighed again.

From these two results the S.G. of the liquid is calculated from the formula:

$$\frac{W_1 - W}{W_2 - W}$$

where W_1 = Weight of tube filled with liquid.
W_2 = Weight of tube filled with distilled water.
W = Weight of a given volume of the liquid.

Hare's Apparatus.—This comprises an inverted U-tube having a middle limb. The opposite tubes each dip into the liquids whose S.G. is to be compared. On sucking gently at the middle limb the respective liquids are drawn into the tube and the tubes sealed by a clip.

The heights of these liquids above the levels of the liquid in their reservoirs are inversely as their respective specific gravities.

The Hydrometer.—This comprises a hollow glass tube which is weighted at the bottom and has at the top a long graduated scale upon which specific gravities can be read off directly. There are various types, such as the lactometer, alcoholmeter, areometer, etc. All these are usually graduated for temperatures of 15·5° C.

Viscosity.—Viscosity refers to the stickiness or tenacity of a liquid. All liquids, whether thin or thick in consistency, possess viscosity, which is the measure of the internal friction of a liquid, or its resistance to flow. A knowledge of the viscosity of a liquid is of importance in estimating the size of pipes through which the liquid has to flow, and the pressure to be applied to the liquid during its circuit of any pipe-line system. It is a measure of the internal molecular resistance of the liquid.

The absolute internal friction of a liquid, or its inherent viscosity, is, in theory, considered to comprise the force necessary to move a layer of the liquid of 1 sq. cm. area over another liquid layer of equal dimensions and situated 1 cm. distant, the first liquid layer moving over the second layer with a velocity of 1 cm. per second. This definition gives the viscosity of a liquid in absolute units (C.G.S.).

This absolute force can be measured by estimating the rate of flow of the liquid through capillary tubes under constant pressure. Thus, in one formula the absolute internal friction (viscosity) (n) is given by:

$$n = \frac{\pi p r^2}{8vl}$$

where p = Pressure (in grammes per square centimetre) of the liquid.
r = Radius of the capillary tube.
l = Length of the capillary tube (in centimetres).
v = Volume (in cubic centimetres) of the liquid which passed out in time t seconds.

Unit of Viscosity.—The unit of viscosity has never been settled—physicists and physical chemists favour the absolute viscosity, determined on the above-mentioned principle, by one type of capillary-tube system or another, such "absolute viscosities" being expressed in C.G.S. units. They favour the expression "specific viscosity," which is the absolute viscosity of a liquid referred to water at 0° C., or at the temperature of the viscosity determination.

Absolute viscosity values, while they may be scientifically more accurate and satisfactory, are generally very small numerically. Thus, for example, the absolute viscosity of water at 0° C. is 0·01797, while at 20° C. this value becomes only 0·01004. There has been a tendency to multiply such "absolute" viscosity values by 100 and to take the "specific viscosity" of water at 20° C. as being 1.

Industrial Viscosimeters.—These vary in detail, but the majority of them follow a well-known principle in viscosity determination, viz. the measurement of the amount of fluid which will fall through a standard aperture or jet at a given temperature and in a given time, or, alternatively, the measurement of the time taken by a given quantity of liquid to fall through a given jet or aperture at a given temperature.

The Redwood viscosimeter is a well-known instrument in England. It operates on the principle of estimating the time taken for a standard volume (50 C.G.S.) of a liquid (at any given temperature) to drop through an agate jet.

The Engler viscosimeter, an instrument of German origin, puts into practice a similar principle, although in a different way. So, too, does the Saybolt viscosimeter, which is the instrument at present popular in America.

None of these industrial viscosimeter methods gives any direct determination of the actual internal friction of a liquid or of the specific viscosity of the liquid. The industrial viscosimeters give merely their own particular readings, which are highly individual and are absolutely non-comparative. The higher the number of degrees of viscosity of a liquid as measured by these viscosimeters, the greater the consistency of the liquid, but each of the scales is arbitrary, and hence the industrial viscosimeter reading has no fundamental scientific basis.

Compressibility of Fluids.—For practical purposes fluids are considered as incompressible. This is not quite true, for, if 1,000 c.c. of water are subjected to a pressure of 1 atmosphere, the mass of liquid will be diminished by 0·05 c.c. in volume, thereby becoming 999·95 c.c. When a mass of water, or any other liquid, is compressed, it immediately assumes its original volume when the pressure is released, no matter how long the pressure is applied. Gases are, of course, compressible to a great degree.

Capillarity and Surface Tension.—If liquid is confined within a narrow vessel, it will be found that the surface is slightly concave. This is known as the meniscus, except in the case of mercury where the surface becomes convex. The meniscus is apparent only in the case of liquids which "wet" the sides of their vessels. A liquid which does not do this, such as molten lead or mercury, does not cling to the sides; it tends to withdraw itself from the sides. This property is known as surface tension, and it is due to attractive forces set up by the molecular particles present in the surface layer. These cause a film of the liquid to adhere to the vessel side and to draw some of the surface layer of liquid to them.

If a narrow tube is held vertically in contact with the surface of water in a vessel, the water will rise up instantly within the tube, and the water level within the tube will be higher than the water level outside the tube. The narrower the tube the greater will be this difference in water level. Any tube which has a bore of less than $\frac{1}{20}$ in. is known as a capillary tube. This is due to capillary attraction. In the case of non-wetting liquids, such as mercury, if a tube is dipped below the surface of it, the tube forms a depression in the mercury surface, and the mercury does not rise to the level of the mercury outside it. The smaller the tube the greater the depression.

Surface Tension.—Surface tension is not the same for all liquids. With the

exception of mercury, the surface tension of pure water is higher than that of any other liquid. Scientifically, surface tension has been measured in dynes per square centimetre, and, on this basis, the surface tension of water (at 20° C.) is found to be 72·70 dynes per cm., while that of pure alchohol is only 21·7 dynes per cm. Benzene, a well-known liquid, has a surface tension of 28·85 dynes per cm. at the above temperature. Mercury has a surface tension of 520 dynes per cm.

Siphon.—If the two equal-length limbs of a glass U-tube are filled with water and then inverted so that its ends dip below the surface of water in a vessel, the water will not show any tendency to flow out of the tube. If one of the limbs dips below the surface of water while the other stands over the edge of the vessel, the water will remain stationary in the tube. If the length of the overhanging U-tube limb is increased and suction is applied to it, water will be drawn through it so that the water level of the lower limb falls below the water level in the vessel, and water will at once ascend the shorter limb and will flow out continuously from the lower limb until the liquid in the vessel has fallen below the level of the shorter U-tube limb. This is the principle of the automatic flush, the Soxhlet extractor, and many similar devices.

Liquid Heads and Fluid Pressures.—Fluid pressure is the force exerted by a fluid per unit area. It is sometimes referred to as the intensity of pressure. If the pressure is given in pounds and the area of the liquid in inches, then the "intensity of pressure" will be expressed in "pounds per square inch."

If a liquid be under an even pressure, the intensity of pressure (P) will be given by the expression:

$$P = \frac{x}{y} \text{ lb. per sq. in.}$$

where x represents the total pressure (in pounds) on an area of y sq. in.

At any area or point of a mass of liquid contained in a receptacle, the pressure is uniformly distributed. If to any area of such a mass of liquid a slight increase of pressure is applied, this pressure increase is immediately distributed to all other areas of the liquid.

The pressure of a liquid on the bottom of its containing vessel is the sum of the weight of the water divided by the area of the bottom of the vessel *plus* the weight or, rather, the pressure of the atmosphere on the surface of the liquid, which pressure is faithfully transmitted through the liquid to the floor of the vessel. Since a liquid is subjected to the pressure of its own weight, it follows that the pressure increases with increasing depth of liquid.

Static Head.—The pressure at any submerged area or point in a liquid is governed by the height of the "free surface" or liquid-level above that point or area. This height is known as the "static head" of the liquid, and is usually represented by the symbol H.

The intensity of pressure on any area or point in a liquid may, therefore, be expressed at a pressure in pounds per square inch of the liquid, or as a static head in feet (depth) of the liquid. The intensity of liquid pressure on the sides of a vessel increases from zero at the surface to wH at the bottom of the vessel, the pressure increase on the sides of the vessel being uniform. The pressure of the atmosphere on the surface of the liquid is not usually taken into consideration, but this absolute pressure may be obtained by adding the prevailing barometric pressure to the intensity of pressure at any point in the liquid.

The Piezometer Tube.—The pressure of water or of any other liquid in a vessel or a pipe line can readily be estimated by means of a Piezometer tube, which, in its simplest form, comprises merely a vertical glass tube which is inserted into a vessel or pipe line. The Piezometer or pressure tube need not be straight. It can be curved and even run for some distance in a horizontal position. The vertical height of the liquid in the Piezometer tube is a measure of the pressure intensity of liquid within the vessel or pipe line.

The pressure head at any point in a liquid can be defined as the vertical distance between that point and the "free surface" of the liquid. This pressure head, H, is equal to $\frac{p}{w}$, where p is the pressure per square foot and w is the weight of 1 cu. ft. of the liquid.

HEATING AND VENTILATION

An efficient heating and ventilating system should ensure that the temperature and humidity of the enclosed atmosphere, in summer and in winter, are maintained automatically at an equally comfortable level with a relatively small financial outlay.

In many offices it is impossible to freshen the atmosphere except by the throwing open of windows and doors, thus subjecting the occupants to the influence of draughts, and the problem is to adopt means of reconditioning an otherwise exhausted atmosphere.

Where a large number of people are employed, the temperature of the enclosed atmosphere may rise 10° to 20° F. during the proceedings, and change from one of chilly discomfort to stifling oppressiveness. In the office, and to a lesser degree in the factory, the result of any imperfections in the heating and ventilating arrangements will be observed in the reduced output of effort, the employees being incapable of the mental and physical exertion requisite to enable them to keep abreast of their work.

A point that rises early in the investigation concerns the cost and the sum which may be allocated to this work; the cost will be lower if the proposal is applied to new structures during the process of building than it would be if existing property is to be treated. Further, the decision regarding its control will affect the cost, that by human agency being less expensive than when automatic devices are included, although the latter is without question the better plan to adopt. As any scheme for an existing building will be based on generally similar lines in principle to that for a new structure of similar type, the notes which follow will apply to a new building, and would be adapted to suit the older property.

A number of factors will influence the problem of efficient heating, namely:

(1) Dimensions of office or factory, and number of staff or workpeople engaged therein.

(2) Structure of building, i.e. materials of which the walls, ceiling (or roof), and floors are made, together with thicknesses thereof.

(3) Insulation proposed.

(4) Number and size of windows, and position of these relative to the points of the compass. Also the number and sizes of doors, and their location.

(5) Window design, and particulars of openings available, if any.

(6) Heating medium to be employed, and whether control is to be automatic or by caretaker.

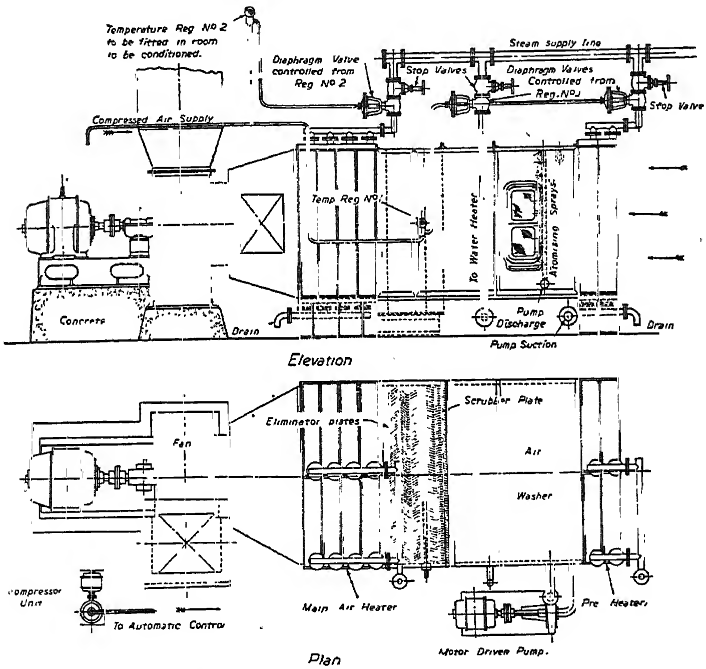
Calculations will be made from the data furnished, for the heat required in B.Th.U. per hour for the office, or other building, to reach and maintain a temperature of, say, 65° F. in winter, making due allowance for the heat given off by electrical machines, lights, and occupants. A debit side will include for that lost through the structure, and also for the chilling effect caused by the frequent opening of doors, if these are numerous or of abnormal dimensions. Heat losses in boiler units alone will run from 10 per cent. to 30 per cent. at least, and further deductions must be made for the inevitable losses which will occur in heat transmission.

For summer conditions, calculations will be made to ascertain the heat accumulation due to sun concentration, workers' body heat, and the electrical equipment, and the volume of air—fresh or reconditioned—which is to be introduced to displace the hot vitiated atmosphere otherwise persistent. A natural way out during hot weather is to open all windows, and if the building is in the country this would be an easy solution; but as most business premises are situated in localities which possess a dirty and a noisy atmosphere, such a practice would be quite unsuitable.

Insulation of Walls.—Insulation of the walls, etc., will be essential if heavy fuel bills for heating are to be avoided during cold weather, and this also can be done much more effectively in new buildings. Various materials are available, a few being detailed below.

Floors.—Cork (1 in. to 2 in. thick) fastened beneath the floorboards.
Ceilings.—Cork (1 in. to 2 in. thick), fibre boards, or felt sheets.
Walls.—Cork or fibre boards, moler bricks, or hollow-tiles.

An excellent scheme, which can also be applied to existing walls, comprises fibre boards mounted on a wooden framework with an air space between the fibre boards and the brick, or stone, wall. This affords good insulation, gives an excellent appearance, and is not costly, though some difficulty may be experienced in regard to the finish around window and door frames in existing walls. If this insulation is done thoroughly, it will be found that the cost is soon recovered in



General arrangement of the central-type Sirocco air-conditioning plant.

lower fuel bills and lost time. The heating of a large building will be effected usually from a central installation, using hot water, air, or steam; and in order to conserve the heat generated as completely as possible at every stage, the insulation of pipes and ducts will be arranged for and maintained in good order.

A point which is sometimes overlooked concerns the heat absorption of the fabric of the building, and since losses to some extent are inevitable owing to the structure not being completely heat-proof, heat units will be expended in raising its temperature also. This partly explains the low temperature prevalent in so many offices and other business premises on the first morning after a holiday or a week-end's suspension of work; the heating apparatus has been allowed to cool down, and has been re-started at too short an interval prior to the staff's return. In the meanwhile the losses have exceeded the heat input, the external atmosphere has absorbed much of the reserve heat held in the walls, and the inner

temperature has dropped to the falling value of the reading from the wall inner surface, which also has a progressively falling level to that outside the building unless the heating apparatus is again brought into service. When heat is generated, the rise of the temperature in the room is retarded through the absorption of further heat units by the fabric, and unless reheating is commenced early enough an unfavourable staff reaction will be inevitable due to the chilly feeling on entering the cold structure.

According to the character of the building, the extent and efficiency of its insulation, and the type of heating apparatus, so the cooling and reheating will be rapid or slow, and where a long delay is registered, a building is said to have a long time lag. In the case of large and massive stone buildings, such as the larger cathedrals where the walls are extremely thick and the windows relatively small, heat losses are low, and such structures are often regarded by experts more in the nature of heat conservers, that received in the hot summer months being given out during the winter; as the result, the temperature within these buildings may easily be kept at a constant level.

On the other hand, modern buildings are considered by some experts to be more in line with good design if the insulating measures adopted permit more rapid accommodation to the requirements of the users; a warm spell in, say, February, can be particularly embarrassing in a building which involves a lapse of two to three days for the internal temperature to become adjusted to a sudden external change, and the possibility is that a reversal of conditions will occur before the inner temperature can be corrected suitably. A useful practice is to graph the fall in the thermometer readings which occurs in the office or shop after the heating apparatus is cut out, against another graph giving the external temperature readings over the same period. Such graphs can become useful references, besides rendering considerable assistance to the party responsible for the proper maintenance of the temperature. Where a workshop is in regular operation for the entire day (twenty-four hours) the problem is less difficult to solve from a heating standpoint, but the fuel bill will naturally be much heavier in the winter season.

A variety of heating systems are in operation at the present time, but these may be classified broadly under two heads:

(1) Those which consume the fuel and radiate the heat directly in the room or building to be heated; and

(2) Those which include a central heat generator stored in some remote part of the building, the heat (from water, steam, or air) being conveyed to the different compartments involved in the scheme.

The first list caters for comparatively small buildings, offices, etc., and includes coal (with anthracite) and coke fires and stoves, gas and oil stoves and heaters, and electric radiators; these are less economical and in some cases involve more labour proportionately than the larger systems, but have distinct advantages in regard to their speed of heating and cooling, as well as the ease of control. Occasionally one sees large workshops warmed by coke radiators, but this is a somewhat primitive method and has little to commend it except its low initial cost.

In the second group come the hot-water radiators and pipes fed from a separate boiler centrally situated; steam radiators operated on the vacuum or pressure system; air ducts with warm air fed under pressure from a central heater, the air being filtered previous to being heated and circulated:

(*a*) By ducts situated at a relatively high level, with other outlet ducts at, or near, floor level to return the air after cooling in its fall; or

(*b*) Through grids situated at a lower level, and arranged to eliminate draughts from windows, etc., wherever possible.

Other schemes are available, but the warmed-air arrangement is probably the best for workshop application, care being taken to place the duct outlets in the most favourable position and inclination, and to include a suitable air-conditioning plant in the layout whenever possible. The latter is particularly desirable where female operatives are employed, and a shop which has a continuous supply of fresh, warm air in the winter months will compare more favourably than one heated in the more primitive fashion, in so far as time lost through sick leave is concerned.

Air Conditioning.—The subject of air conditioning, though comparatively new to Great Britain except for a few applications, is well established in the U.S.A., and figures are available which show beyond question that on many days in the summer it becomes a vital necessity in buildings or rooms where a large number of people forgather. Air conditioning is virtually the artificial and continuous reproduction within an enclosure of an ideal climatic atmosphere in which fresh, clean air is always available at the correct temperature and degree of humidity, and subject to continuous, though slow, movement. To-day, as the result of experience, these conditions can be achieved with certainty in a practical and efficient manner with automatic control, under surroundings that would seem to defy the possibility. The value of the process lies either in:

(1) The promotion of uniform and economic production in numerous manufacturing activities; or

(2) The attainment of well-being and a sense of physical fitness, whereby workers become more efficient at work and more capable of appreciating and benefiting from the various social amenities indulged in during leisure hours.

In many processes a correct atmosphere is imperative if success is to be attained in the manufacture of the speciality produced, some buildings calling for the maintenance of an atmosphere having extreme cold, heat, or moisture as its predominant feature. Such a factory may have the latest in machinery for the work to be performed, yet lack the correct atmospheric conditions; in such a case it would be impossible to achieve any output of a satisfactory character. Among such industries may be classed the manufacture of chemicals and dyes, dynamos, jute, paper, printing, silk, tobacco, etc., to name but a small number, and experience has taught the precise temperature and degree of humidity that will ensure success. In office life, a fresh atmosphere at correct temperature and humidity will ensure a staff capable of responding to any reasonable call, and maintaining their output while yet making no serious demand on their reserve energy.

Central Installation.—Plants for achieving the benefits enumerated above may be central or local, i.e. situated at a point whence several buildings or apartments may be served at one and the same time; or placed within the enclosure whose atmosphere is to be treated.

A further gain afforded by a modern installation is reflected in the improved health of the workers, as all air drawn from the building is completely cleansed of dirt, harmful bacteria, and germ-infected particles. Furthermore, distribution and circulation of the fresh air is effected in such manner as to ensure that no stagnant air can remain, nor unpleasant circulation—draughts—obtain. To achieve the most successful results, the equipment must be capable of compensating for the effects caused by infiltration of exterior air, which in winter lowers the temperature and absolute humidity of the reconditioned air within, and in summer produces the opposite result.

Air Washer.—One of the main components in an air-conditioning scheme is the air washer. This is capable of operating with any pressure of steam up to 200 lb. per sq. in., and in conjunction with automatic thermal control. The main casing, or spray chamber, in which the incoming air is cleansed and cooled, houses the atomising spray nozzles and supply pipes thereto. At the discharge end of the chamber scrubber plates and eliminator plates are fitted, the former effecting final cleansing of the saturated air stream, while the latter remove any moisture particles which remain. Glazed inspection doors for access and internal electric light fittings for inspection are standard features in some units. The spraying nozzles are fed with water which is discharged under pressure in a finely atomised state, the resultant spray completely filling the chamber in the form of a thick mist. Intimate contact between air and water particles is maintained, giving effect to the triple actions of cleansing, heat transfer, and saturation.

An alternative design of air washer has a pre-heater at the inlet, on the right-hand side, and a main air-heating battery at the outlet on the left-hand side. The pre-heater controls the saturation temperature and the main air-heating battery is used for maintaining the desired inside temperature. The air washer combines a system of water-atomising nozzles and supply pipes, at the air-inlet end, with a nest of zigzag scrubbers at the delivery end for arresting the moistened dust and other impurities in suspension in the air stream. Suitably placed

eliminator plates remove any free moisture entrained in the air, and drain it back to the galvanised tank which forms the base of the set. From this tank the water, after being filtered through a strainer, is recirculated to the spray nozzles by a centrifugal pump electrically operated. Easy access to the "mist" chamber is achieved through a watertight door, and the functioning of the set can be inspected by windows in this door in conjunction with the electric-light fitting inside the washer.

Air Filters.—A scheme of air filters, with heater and circulating duct, comprises a fresh-air inlet duct fitted with a recirculating damper; a unit heater with electrically driven fan, and an air-delivery duct with a 16-cell "throwaway"-type air filter fixed over the outlet. The fan draws air over the heater (steam or hot water), and discharges it into the room to be ventilated via a short length of duct and the cells of the air filter. The filtering medium consists of a non-inflammable pad of all-metal wool substance which can be thrown away when dirty and replaced at nominal cost.

The recirculating damper on the fresh-air inlet duct has a two-way connection; when this is open air is drawn from inside the room and recirculated through the heater, enabling the temperature to be raised quickly in early morning; when the damper is closed, fresh air is drawn in from the outside.

Most systems of air conditioning involve extensive lines of ducting to carry the air to the numerous distributing points, and if the scheme is for a new building these can be built into the structure with a more pleasing effect. The outlets must be correctly proportioned to effect a silent discharge at low velocity through grilles or other form of opening, and a scheme which is greatly favoured ensures a slight pressure being built up in the enclosure under treatment, in order that no inlet air can be admitted from the exterior. This effectively overcomes any risk of draught from windows or doors, and gives excellent results. Naturally, a certain amount of fresh air must be admitted, since it is rarely possible to continually recondition all the air in circulation without any loss, but this extra supply is drawn into the return ducts at the most convenient point.

During hot weather, artificial cooling of the air must be resorted to; this may be accomplished by the fitting of brine or other cooling coils within the air-washer casing, or by precooling the water supply.

For smaller enclosures—conference room, office, shop, etc.—a unit set may be fitted. These are extremely compact, occupy small space, are capable of being transferred to other sites if required, and enable the advantages of conditioned air to be enjoyed with moderate financial outlay.

The foregoing notes merely fringe what is an extremely big subject, as well as a vital one for the health of the workers. Much research work has been carried out in this field, and numerous equipments in different climates yield valuable data on which the requirements of new problems may be based. Possibly the best augury for future success lies in the fact that the interests of employers and workers alike are involved, the latter having their employment under ideal conditions, and the former a staff of workers physically and mentally alert.

Ventilation Units.—A supply of 1 cu. ft. of pure air per second is a liberal allowance for one person (= 3,600 cu. ft. per hour), and may be considered as a "unit of ventilation." The temperature of 3,600 cu. ft. supplied to him would be raised to the extent of 4° F., under ordinary circumstances, by the person who uses it.

A circular aperture 6 in. in diameter in a thin plate requires a head of 1 ft. of air (0·015 in. of water) to force through it 1 cu. ft. of air per second. A unit head (0·015 in. water pressure) maintains unit flow (1 cu. ft. per second) through unit resistance (circular aperture 6 in. in diameter in thin plate), but the head required to maintain a flow through a given resistance is proportional to the square of the flow, and the resistance is inversely proportional to the square of the area of aperture, i.e. inversely proportional to the fourth power of the linear dimensions for thin-plate apertures of similar shape.

The unit of heat is that quantity of heat required to raise the temperature of 1 lb. of water 1° F. One pound of a good bituminous coal will provide more than 13,000 British heat units (or B.Th.U.s), and the total heat given out by a definite quantity of any combustible matter is expressed as its calorific value.

Constituents of Coal.—These are mainly carbon, ash, sulphur, and hydrogen, and the proportions of these ingredients vary considerably according to the grade and type of coal, but for practical purposes it is necessary to consider only ash content, which is a combination of various oxides—silica, lime, etc.—and carbon.

Pressure Gauge.—In plants where several thousands of tons of fuel may be burned per annum in a single boiler-house, the use of instruments as an aid to economy has become urgently necessary.

All boiler plants are fitted with a pressure gauge, because this is obligatory. The pressure gauge shows only the pressure at any given moment, but does not give any indication of how much steam is being taken from the boiler.

Rate of Evaporation.—The chief factor which must be known and which must be continually watched and maintained is the "evaporation lb. water per lb. fuel." The purpose of any boiler is to convert as little fuel as possible into as much steam as possible. If a boiler is found to be evaporating, say, 9 lb. of water for every 1 lb. of fuel used, then that boiler is working fairly efficiently, and is producing twice as much useful work as is a boiler giving only, say, 5 lb. per 1 lb. of fuel. These figures are known as the "actual evaporation," and are a useful and accurate indication of the thermal efficiency of the plant. If any justification is needed for insisting on fuel economy in boiler plants, it might be mentioned that in a special test of a small battery of Lancashire boilers in a pottery concern the evaporation was less than 3 lb. of water per 1 lb. of fuel.

Evaporation Charts.—Only two simple measurements are required to arrive at the actual evaporation: firstly, the weight of the fuel used; and, secondly, the weight of the water taken by the boiler over the same period. Having obtained these two figures, one has merely to divide the total number of pounds of water used by the total number of pounds of fuel used to get the figure required. To carry out a short initial test, say, over a period of eight working hours, the fires should first be cleaned and levelled off, and the level marked with a chalk line on the boiler front at each side of the door. The purpose of this chalk mark is to enable the fireman, at the conclusion of the test, to make his fires up to the same level as he commenced with.

All coal used during the eight hours in question must be measured, and this is most conveniently done by using a suitable receptacle such as a bin, which can be filled level with the top and weighed. Weigh the bin full, and also empty, and thus you can measure the weight of coal in the bin. Thereafter, as each bin is used on the fires, put a chalk mark up on the wall, and thus at the end of the test you can see how many bins of fuel have been used, and therefore arrive at the total weight used. This method is, of course, suitable for only small plants: where large plants are concerned the number of truckloads or cartloads used will give the figure required.

Measuring the Water.—If the water company's meter serves the boiler only (which is unlikely), then that meter can be used, but in the majority of cases it is necessary to install a suitable water meter in the feed-pipe to the boiler. At the commencement of the test note the reading of the meter, and again take its reading at the conclusion, and the difference in these two figures will give you the number of *gallons* of water which the boiler has evaporated during the test. Here again, however, it is necessary to make a note of the water-level in the boiler at the start and see that the level is the same at the end.

Assume, for example, that these figures are: coal burned, 43 cwt. 2 qrs., and the number of gallons fed to the boiler, 3660. Fuel weight thus equals 4880 lb. Each gallon of water weighs 10 lb., so the weight of the water is 36,600 lb. The evaporation factor (actual) in this case would therefore be:

$$\text{Evaporation factor} = \frac{36{,}600}{4880} = 7\cdot5.$$

For a Lancashire boiler, hand-fired with natural draught, this might be considered a good figure since, assuming the calorific value of the fuel to be 12,000 B.Th.U.s, the average steam pressure 75 lb. and the feed-water temperature 120°, this would represent an over-all thermal efficiency of somewhere about 70 per cent.—quite a good figure for the type of boiler in question.

This boiler has evaporated approximately 458 gallons per hour: assuming that the load remains constant and the boiler is in service for 350 hours per month, then the total amount of fuel burned will be:

$$\frac{458 \times 10 \times 350}{7 \cdot 5} = 95 \text{ tons } 8 \text{ cwt. (approx.).}$$

Supposing the evaporation factor has dropped to 6 lb., the load remaining constant as before, the following equation applies:

$$\text{Fuel consumed} = \frac{458 \times 10 \times 350}{6} = 119 \text{ tons } 5 \text{ cwt.}$$

With coal being delivered and fired every day, this increase in fuel consumption would not be easily noticed—certainly not until a great quantity of fuel had been wastefully consumed: in this case, waste at the rate of about 300 tons per annum.

A typical evaporation chart is shown in Fig. 1. It will be noted that the evaporation factor tended to improve after the first seven weeks, partly owing to a better fuel being delivered and partly due to an improvement in load conditions. In the eleventh week the curve began to drop and was still lower in the thirteenth week; this was due to a change in firemen, but steps were taken to give instructions in the proper care of the fires, with the result that the curve soon returned to normal.

From and at 212° F.—Whilst the chart is excellent so far as it goes, every boiler owner should go farther and occasionally carry out much more comprehensive efficiency calculations. *Actual* evaporation figures have so far been dealt with, but the boiler technician deals with "from and at 212° F." figures, and it is necessary to understand this point before complete thermal-efficiency figures can be worked out.

In a vessel in which water is boiling (as in a steam boiler), the greater the pressure in that vessel the greater is the amount of heat that is necessary to release the vapour to form steam. Boilers do not all work at the same temperatures and pressures, and it would not do to treat all boilers as if they were working under similar conditions, so when preparing a thermal heat account consideration has to be given to the quantity of heat put into the steam. The amount of heat required to convert water at boiling temperature, 212° F., into steam at the same temperature is taken as the basis; the extra heat in the steam at working pressure is expressed in terms of the extra water that heat would evaporate at 212° F. These figures have been calculated for all pressures. The total evaporation thus arrived at is called the evaporation "from and at 212° F.," the relationship between this figure and the "actual evaporation" being known as the Factor of Evaporation.

Thermal Efficiency.—The things to be measured in order to compute the thermal efficiency of a boiler plant are as follow:

Pressure of steam.
Total quantity of water used.
Total quantity of fuel burned.
Water temperature at inlet and outlet of economiser.
Calorific value of the fuel.
Steam temperature if superheated.

A test of this nature should be taken over a continuous period of at least eight hours, and each quarter of an hour note should be taken of the steam pressure on the gauge, the water-meter reading, etc., and, of course, all coal fired to the furnaces must be weighed. The chief difficulty would be to determine the calorific value of the fuel, although the coal-supplier might be able to help in this respect. A fairly good-quality coal will be somewhere round about 12,000 B.Th.U.s per pound.

Having taken the various readings each quarter of an hour for the whole period of the test, an average should be taken of each reading, and for the purpose of illustration assume these to be as follow:

Actual evaporation, 6·5 lb. water per lb. fuel.
Feed-water temperature, 60° F.
Total heat in steam (from steam tables), 1196 B.Th.U.s.
Steam pressure, 170 lb. per sq. in.
Temperature of steam, 375° F.
Calorific value of fuel, 12,300 B.Th.U.s.

The first thing to compute is the evaporation of the fuel used if 100 per cent. efficiency were achieved, i.e. the evaporative value of the fuel. This is simply

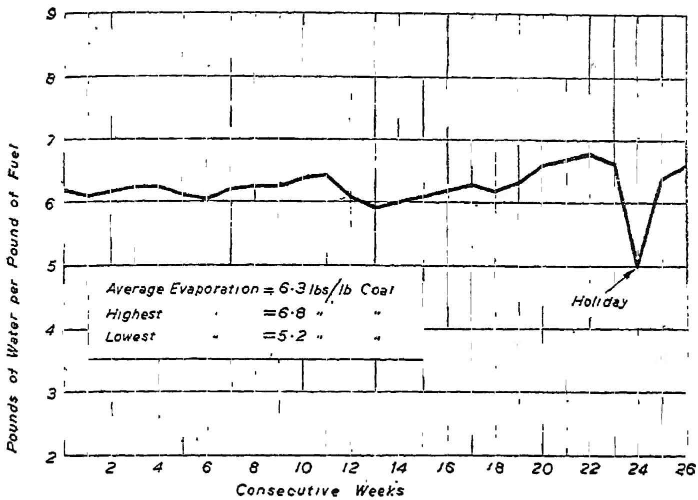


Fig. 1.—" Actual " evaporation chart, indicating boiler efficiency from week to week.

the heat value of the fuel, 12,300 B.Th.U.s in this case, divided by the latent heat in steam, which is a constant and is 970. In our assumed case, therefore, the evaporative value of the fuel would be :

$$\frac{12,300}{970} = 12{\cdot}7 \text{ lb.}$$

The formula for the evaporation-factor calculation is :

$$\frac{H - h}{970}$$

where H = Total heat in the steam at the stop valve.
h = Heat in the feed-water.

(Both these figures can be taken from steam tables, and will be found to be 1196 for H, and 28 for h.)

Therefore, in the example given the factor of evaporation is :

$$\text{Factor} = \frac{1196 - 28}{970} = 1{\cdot}2$$

and therefore the equivalent factor from and at 212° F. is the actual evaporation, 6·5 lb., multiplied by the factor, 1·2, which gives us the final figure of 7·8 lb.

Now calculate the thermal efficiency of the plant, using the following equation :

$$\frac{\text{Factor of evaporation} \times \text{actual evaporation} \times 100}{\text{Evaporation value of fuel}}$$

which is,

$$\frac{1{\cdot}2 \times 6{\cdot}5 \times 100}{12{\cdot}7} = 61{\cdot}5 \text{ per cent. approximately.}$$

In this case, 38·5 per cent. of the total heat in the coal burned is lost, the losses being due to one or more of the following causes: (*a*) heat carried away by the stack gases, which will be shown by high temperatures at the base of the stack; (*b*) imperfect combustion, or (*c*) excess primary air. The above takes no account of any economisers or superheaters, which, had they been installed on this boiler, may have shown an improvement of 12 per cent.

Where the plant is fitted with economisers and superheaters, then the method of computing the thermal efficiency of the boiler is a little more complicated, as follows:

Firstly we have to compute the evaporative value of the fuel, as was explained in the last example. But the factor of evaporation is now arrived at by the formula:

$$\text{Factor of evaporation} = \frac{H - h + h_s}{970}$$

where H = Total heat in the steam.
h = Economiser inlet temperature, 32°.
h_s = Difference between stop-valve temperature and that due to the pressure of steam as obtained from steam tables multiplied by the specific heat of steam, which is 0·6; in other words, the heat added in the form of superheat.

Having obtained the correct factor of evaporation in this way, the remainder of the computation is as in the last example.

The heat loss through the stack at varying percentages of CO_2 at given flue temperatures is found from the formula:

$$H = \frac{K(t_1 - t_2)}{C}$$

where t_1 = The boiler-house temperature in ° F.
t_2 = Flue-gas temperature at base of stack in ° F.
C = Percentage of CO_2 in the flue gases.
K = A known constant.

Costing.—To ensure that the coal used is the most economical for the boiler in question, the cost of the fuel has to be taken in conjunction with the amount of water evaporated by each pound of it, and the following formula gives the cost per thousand pounds of steam:

$$\frac{\text{Coal cost shillings per ton} \times 1000}{\text{Actual evaporation} \times 2240} = \text{Cost in shillings per 1000 lb. of steam.}$$

Beyond the elementary fact that to burn coal one must burn air also, it is not generally understood—even by those in charge of boiler plants—that to control the *quantity* of air is equally important as controlling the pressure of steam. To obtain *perfect* combustion of the fuel fed to the furnace, the quantity of air necessary *in theory* is approximately 12 lb. of air to each 1 lb. of fuel, but, as in so many other things, theory has to give place to practice, and in practice we have to provide a considerably greater proportion of air.

If, however, we could attain theoretical perfection, the result would be that the gases leaving through the flues would consist almost entirely of CO_2 (carbon dioxide), plus nitrogen and water vapour.

If the air supply is limited to the theoretical 12 lb. per 1 lb. of fuel, owing to inadequate admixture of the molecules of carbon in the fuel with the molecules in the air, certain quantities of carbon monoxide (CO) would be formed, which in itself is a great source of waste. One pound of carbon converted into CO will produce only some 4000 B.Th.U.s, whereas the same quantity of carbon converted into CO_2 will produce over three times as much heat, i.e. some 14,000 B.Th.U.s. In fact, 1 per cent. of CO in the flue gases means a loss of about 4 per cent. of fuel, a very substantial loss in a battery of boilers consuming perhaps tons of fuel a day.

Too little air and *too much* air are sources of waste. What we have to aim at, therefore, is to obtain as high a percentage of CO_2 as possible, consistent with a

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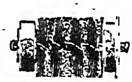

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very low CO content and a low stack temperature. For that reason, it is essential that the plant be fitted with some means of recording the CO_2 content in the flue gases: to try to run a boiler plant without a CO_2 recorder is like the captain of a ship trying to navigate it without a compass. If the CO_2 content and the temperature at the base of the stack are known, then the sensible heat loss can be determined from the table given in Fig. 2. For example, assume that the CO_2 reading is 8 per cent. and stack temperature (less atmospheric temperature) is

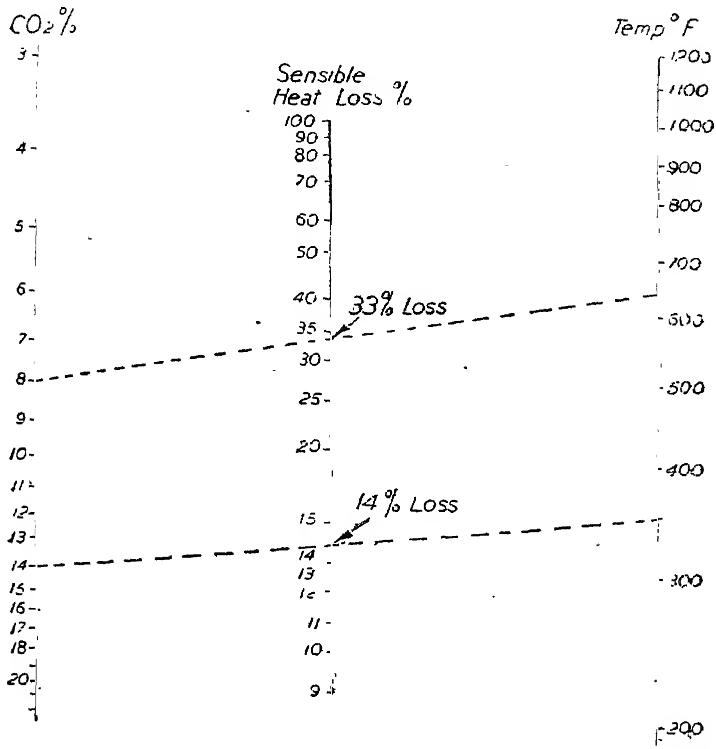


Fig. 2.—Chart showing sensible heat losses for given quantities of CO_2 in flue gases and given flue-gas temperatures. Note: The measured flue-gas temperature should be reduced by the atmospheric temperature, e.g. a measured temperature of 800° F. would, if outside temperature is 60°, be reckoned as 760° for use on this chart.

650° F., then a line drawn between the relative points on the first and third columns will intersect the middle column at roughly 33 per cent., i.e. the boiler is working at not more than 60 per cent. efficiency. If, by controlling the air the CO_2 reading is increased to 14 per cent. and the stack temperature decreased to, say, 350° F., the sensible heat loss is now only about 14 per cent.

Controlling the Air.—Air enters the furnace in two ways, either through the ashpit opening and up through the fuel-bed (which is known as the "primary" air), or through the fire-door and over the top of the fire-bed (known as "secondary" air). In considering the matter of excessive air it is usually this

"secondary" air that gives trouble, and in most boilers any efforts made to reduce this source of air will be amply repaid in saving of fuel and the physical effort of shovelling it on.

A certain amount of secondary air is essential, but only so much as is necessary to burn up any volatile matter or combustible gases given off by the fuel. With a coal of a volatile nature, large volumes of volatile gases will be given off immediately after feeding green fuel to the fire, but as the fresh fuel becomes incandescent these volatiles will fall off. Consequently it will be seen that immediately after firing, quite large volumes of secondary air may be required to burn the volatiles and prevent smoke formation; but that the secondary air requires reduction as the green fuel begins to burn properly. Therefore, ready control of secondary air is of great importance since (*a*) too little immediately after firing may cause smoke and waste, and (*b*) too much when the fuel is burning through may cause waste through heat being carried away to the flues.

Most fire-doors are provided with a louvre of some kind for adjusting secondary air.

Coke and Anthracite.—Where low-volatile fuels are being burned, very little secondary air is required—in fact, it may be said that on most installations quite enough will find its own way in, even when the louvres are closed. Even so, the fire-doors, brickwork, etc., should be checked to see that as much secondary air as possible is excluded, for, taking an imaginary case where there is absolutely no leak of any description, you would require a secondary air opening of *only* 2 *sq. in.* per cwt. of fuel burned per hour. In other words, eliminate as much secondary air as you can, enough will still get in despite your efforts.

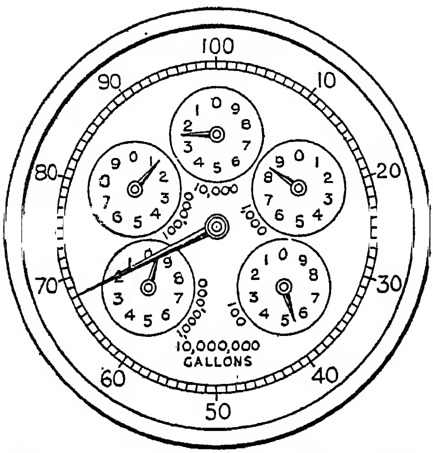


Fig. 3.—Reading a water meter. Note that the small dials are alternately clockwise and anti-clockwise. The reading of the above meter is 128,568 gallons.

Bituminous Coal.—In this case insufficient secondary air will cause some of the volatile matter and carbon monoxide to escape unburnt, which, as already explained, means waste and the probability of a healthy plume of black smoke.

Draught Regulation.—The following may be contributory causes of excess air being present in any boiler:

(1) The size of the coal and/or depth of the fuel-bed may be unsuitable.
(2) The grate area may be too large for the quantity of fuel burned.
(3) The grate may not be properly covered with a level bed of fuel.
(4) The draught may not be properly regulated by the dampers.

Large lump coal is, for instance, quite unsuitable for use in boiler furnaces; it should always be broken down before being fired to a size not exceeding 4 in.—2 in. is even better.

In regulating the air supply to a boiler by means of the stack dampers, a suitable size of grate area is vitally important. There are too many cases where because there happen to be two boilers side by side both are fired with small, inefficient fires, while much better results would be secured, together with a much greater fuel economy, by taking one boiler out of commission and stoking the other one up to capacity. Under-fired boilers are a source of fuel waste, since not only is the boiler working inefficiently through being under-loaded, but there is always the greatest probability of holes and thin places appearing in the fire-bed.

The object of regulation by the dampers is to burn the fuel at the desired rate with *as little excess air as possible,* thus maintaining a high furnace temperature and an increased rate of heat transmission by direct radiation from the fire. The recommendations concerning air supplies may be summed up as follow:

(*a*) Regulate the inrush of secondary air by carefully sealing all leaks and adjust louvres in fire-doors so that they can be controlled easily and to small openings.

(*b*) Regulate primary air by close adjustment of stack dampers so that the fuel is burnt with the minimum of excess air.

(*c*) By controlling both primary and secondary air, strive to obtain CO_2 readings of not less than 12 per cent.—even if this means reducing the grate area.

(*d*) Keep the firegrate covered all over with a level bed of fuel free from holes or thin places. Frequent use of the rake will help you to do this, particularly in keeping the back of the grate well covered near the bridge.

(*e*) Avoid formation of smoke by firing frequently and regularly in small quantities. The habit of firing large quantities of green fuel at irregular periods is responsible for much smoke and waste of fuel. Keep all secondary-air vents closed except immediately after firing, when they should be opened until the green fuel becomes incandescent and volatiles cease to be given off.

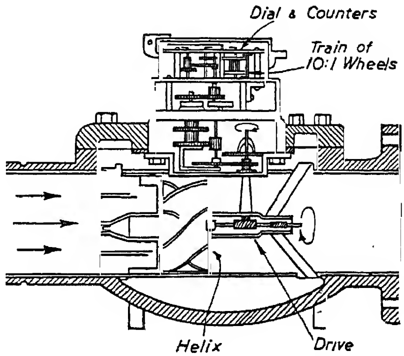


Fig. 4.—Section through horizontal helix water meter, showing how the flow of water impinging on the helix imparts to it a rotary motion which is transmitted through a mechanical drive to a train of 10 : 1 wheels to which pointers are fixed indicating units, tens, thousands, etc., of gallons passing. The speed of rotation is proportional to the flow and consequently to the quantity of water.

Safety Valve.—Under the Factory Acts every boiler *must* be fitted with a safety valve, a steam-pressure gauge, and a water gauge. These fittings are, however, intended only as safeguards, and are not intended—and never can be—sufficient aids to correct boiler management. They indicate only two things: (*a*) that the pressure of steam is not exceeding the maximum pressure for which the boiler was designed, and (*b*) that the level of water in the boiler is not below danger point. Much more than this is needed; one needs to know at the very least the quantity of water that is being evaporated by the boiler in return for the quantity of fuel being burned. To ensure that the least possible amount of fuel is being used to produce the quantity of steam required, it is necessary to know the thermal efficiency of the plant, including the draught conditions under any given conditions of load, the quantity of CO_2 in the flue gases, the temperature at the base of the stack, and so forth, and none of these things can be known unless proper instruments are fitted. The lack of such instruments and the knowledge to be gained from them may easily mean that the boiler is using *twice as much fuel* as is really necessary; the consequent loss in money and the strain on the country's coal resources in such cases are out of all proportion to the useful work which the boiler is doing.

Water Gauges.—Most of these gauges are of a standard pattern, and to test them it is necessary to shut the bottom cock, open first the drain and then the top cock. If there is no stoppage, steam will blow through from the top of the water in the boiler. By closing the top cock and opening the bottom water should be forced out. If the water returning to the glass is at all sluggish in reaching the water-level, the plug screws provided on the fitting should be removed at the first opportunity and cleared with a ½-in. rod. The gauge glasses (which should be kept clean at all times and renewed every six months) must be in position when

the above test is carried out. Finally, in most cases of furnace crown collapse or flue tube bulges, the trouble is traceable to choked-up water gauges giving false readings.

Water Meters.—The "actual evaporation" of a boiler (which is the number of pounds' weight of water evaporated for each pound of coal burned) is a reliable way of keeping a check on the performance of the plant, but is, of course, only possible where (*a*) the quantities of coal used are weighed and recorded, and (*b*) where the weight of water evaporated is known.

These instruments record the amount of water passing in *gallons*, and since one gallon of water weighs 10 lb., multiply the number of gallons by 10 to arrive at the *weight* of the water.

The standard water meter, of which there are many forms, works on the simple principle that the flow of water passing through the body of the meter impinges on some form of fan whereby a rotary motion is caused, the speed of which is proportional to the rate of flow. In all meters of this type there is a chamber through which the water flows, this having suitable connections for fitting into the feed-pipe. The fan, or other responsive element, is contained in this chamber and the rotary movement of the fan is transmitted through a train of wheels to a counter, which measures the total flow in gallons.

Inferential Meters.—Water meters may, generally speaking, be classified under three headings, these being the positive, semi-positive, and inferential types, but the last is the most commonly used for boiler plants. "Inferential" meters are so named since the rate of flow is inferred from the velocity.

Again, this type of meter consists of two separate groups, known as the "fan" type and the "helix" type. In the former the fan is mounted vertically in the flow chamber, the water impinging on it through tangential passages in such a way that the rotation of the fan is proportional to the velocity, and hence the quantity of the flow. This rotation is transmitted, through a primary train of wheels, to a secondary train, each of the latter being 10 : 1 ratio. To each of these wheels a spindle and pointer are fixed, these being brought up through a dial on which is a separate indicator per spindle, these registering in units, tens, hundreds, thousands, and so on. They are read in much the same way as the familiar electric-light or gas meter, as shown in Fig. 3, although there are cyclometer types which are easier to read but more expensive to manufacture.

The fan type of meter is usually confined to sizes from ½ in. to 2 in.; for larger-size feeds, the "helix" form is used, in which the rotor axis is usually horizontal and in line with the centre of the main flow. Here again, however, there is a divergence of opinion, since some manufacturers design the helix rotor on a vertical spindle with an upward flow, the idea being that in operation the flow of water lifts the spindle from its lower bearing, thus avoiding undue wear. In practice, both types are efficient, although in the vertical-helix type it may be necessary to change the direction of the flow, which may again involve a larger head loss than would be the case if the more usual horizontal type were fitted. Fig. 4 shows a typical type of horizontal helix meter.

Venturi Meter.—The Venturi water meter consists of a short series of pipes shaped like a *vena contracta*. Tubes are led from the commencement of the contraction, and from the contracted throat to the meter box, where the pressure and volume of flow are indicated.

The Venturi meter may be used for measuring either hot or cold water in bulk; it is adaptable to mains of any diameter and does not restrict the flow; there are no moving parts. The principle of action is based on the "Venturi law" that "water flowing through a pipe of diminishing area loses the pressure which it exerts laterally as it gains in velocity." Consequently water flowing through an expanding cone loses "speed" and regains "head." There is, therefore, in any hydraulic circuit a difference of pressure between a point at the full area of the pipe and the point of least area, this difference being known as the "Venturi head." It is this simple principle, applied in the form of a meter tube and recorder, which goes to the making of a Venturi meter. The meter tube forms part of the pipe line in which it is desired to measure the flow of water, whilst the recording portion consists of a specially designed mercurial U-tube, the two members of which are respectively connected to the "bulge" and "throat" of the tube. The necessary connection between pressure and time is secured by an ingenious combination of float and rack-and-pinion gear.

CONVEYORS

Conveyors are used in most large works to-day to speed up production and avoid handling. They are also used to a considerable extent in the coal industry, where they are capable of handling up to 2000 tons per hour. Conveyors of the single type are made up to 1000 ft. in length and up to 54 in. in width, and they are usually of vulcanised rubber and cotton.

The width of the conveyor is decided by the size of the material for which it is to be used, and the speed is fixed at the lowest at which the desired capacity can be handled. Essentially it consists of an endless belt running over pulleys and supported intermediately by idler rollers and jockey pulleys to maintain correct belt tension.

As a general practice they are troughed on the loaded side, but sometimes they run flat. The goods being conveyed can be discharged at the terminal pulley or at intermediate stages along the length of the belt. The usual arrangement for intermediate discharge is by means of ejector carriages, which may be fixed or mobile, whilst in the case of conveyors arranged to run flat the goods may be discharged by means of fixed ploughs.

The belting can be supplied to handle goods up to a temperature of 300° F. The thickness of the rubber covering varies from $\frac{1}{30}$ to $\frac{1}{8}$ in. on the operative side, and on the back it is usually $\frac{1}{16}$ in. thick.

The material is, of course, of ply construction, and the number of plies is decided by the maximum tension required in the belt. As a general rule, the belt should be equal to a continuous stretch of 25 lb. per in. width per ply. The diameter of the driving pulleys should be (in inches) six times the number of belt plies minimum, and the crown of the pulley should be $\frac{1}{8}$ in. per foot of width. They must, of course, be at least 2 in. wider than the belt, and as much as 4 in., according to the width of the belt.

The usual speed is 300 ft. per min. for narrow belts, and 600 ft. per min. for wide belts, although higher speeds than this are used, i.e. for grain. The pulleys are usually mounted on roller bearings.

The woven and stitched cotton belts sometimes used have the advantage of low first cost, but they are not considered suitable for continuous heavy duty, especially handling those substances likely to cut the surface. Moreover, they are not suitable for handling material of a moist or damp nature, since they are not waterproof, are hygroscopic, and stretch and contract with changes of temperature.

For conveyors which work in the open the Balata belts have been found satisfactory.

Conveyors are sometimes used which are made of wire open meshed, so that dust may be extracted from the products being conveyed.

The horse-power required for driving a conveyor, assuming that ball or roller bearings are fitted, is equal to :

$$\text{H.P.} = \frac{(0{\cdot}15B + 0{\cdot}07M)S + HW}{66{,}000}$$

where S = Speed in feet per minute.
M = Weight of material in pounds on belt.
B = Equals weight of belt in pounds.
W = Weight of material per minute delivered in pounds.
H = Elevated height in feet.

If plain bearings are used instead of ball or roller bearings, the answer to the above equation should be multiplied by 2.

Delays occasioned by the failure of transmission and conveyor belts can be substantially minimised both by preventive precautions and by quick and efficient repairing methods. It is of particular importance to realise this at the present time, when it may be difficult to obtain belt replacements.

The methods with which this section deals are radical ones and are applicable to all rubberised belts for any duty and of any size. The HF process of belt

joining and repairing by vulcanisation enables belt users to ensure the 100 per cent. efficiency of all belt joins, the failure of which is the cause of the great majority of transmission-belt troubles, and to repair conveyor belts *in situ* with speed and certainty, thus avoiding the costly delays due to breakdown or to the time taken in dismantling machinery.

Flush Joins.—It is proposed to deal separately with the two processes of joining and repairing. HF vulcanised joins are flush, a most important point, as the join remains as flexible as the main part of the belt, which can be successfully used for short drives at high speed over small pulleys. The belts are free from noise when running, being in effect endless and having no lap or clumsy connecting device. These vulcanised flush joins are made in position on the plant, unless otherwise desired, and the work can be carried out by any mechanic who follows the instructions provided by the manufacturers of the special vulcanisers used in this process.

The process is applicable to the flush joining of both transmission and conveyor belts, the two ends of the belts being spliced and vulcanised together so that the join is flush on both sides. The method is first to separate the plies of the belt at the ends and then to cut them into "steps" as indicated in the diagrams. The surface of each step is rasped, coated with special flux, and further treated with a film of rubber which is transferred to the surface from a specially prepared material. Both ends of the belt are "stepped" in the same manner but on opposite sides, and are spliced together by engaging the steps in the manner shown by Fig. 1. Without going into every detail of the method, the above gives sufficient idea as to the work required. When the ends of the belt have been spliced together they are inserted between the platens of an HF belt-joining vulcaniser, which is electrically heated and vulcanises the prepared join in a period which varies with the thickness and not with the width or length of the join. All models of the vulcaniser are fitted with an automatic thermostatic control, and an automatic timing switch is also supplied which switches off the current at the end of the requisite vulcanising period.

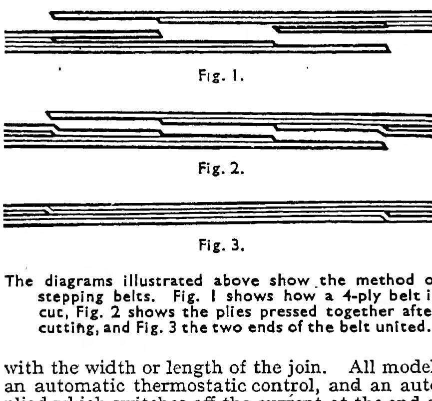


Fig. 1.

Fig. 2.

Fig. 3.

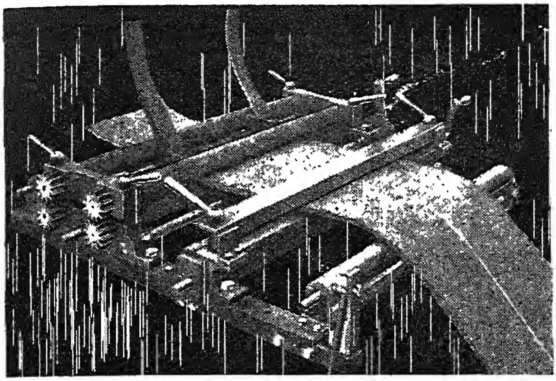
The diagrams illustrated above show the method of stepping belts. Fig. 1 shows how a 4-ply belt is cut, Fig. 2 shows the plies pressed together after cutting, and Fig. 3 the two ends of the belt united.

Repairing Conveyor Belts.—The HF process of repairing belts by vulcanisation is commonly applied only to conveyor belts. The repairs are of a permanent character, preventing breakdown and adding to the reliability of the belt over extended periods. Repairs are carried out in position on the plant without any extensive dismantling. Whether the damage is confined to the rubber surface of the belt or penetrates the canvas, repairs are carried out on one surface only. Should the injury be so severe that the canvas is cut right through from side to side, the method would be to cut out the damaged part of the belt, insert a new piece, and flush-join it at both ends by vulcanising.

When only the rubber of the conveyor belt is damaged, the injured area is cut away with a sharp knife in the form of a bevelled hole, which is then roughened with a rasp. Two coats of the special flux are applied, the hole is filled slightly above the level of the surrounding rubber with flux, and the vulcaniser is applied to the damaged area for the requisite period.

Where the canvas as well as the rubber has been damaged, the rubber is first cut away to expose the canvas and the canvas is then cut away in the form of steps. After rasping and coating with flux, the steps are filled with Plastene canvas, and the surface covered with flux to the level of the surrounding material. The vulcaniser is then applied, as described for repairs to the rubber surface.

THE COMPLETE BELT-REBUILDING EQUIPMENT

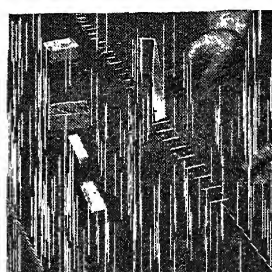


HAYDEN-NILOS PATENT BELT CUTTER

Recover all useful strips and pieces of your old rubber conveyor belts and rebuild them into good serviceable belting. First of all mark off and cut the good pieces with the aid of the Belt Cutter—it deals with five or six yards per minute, trimming both the length and cutting across the belt, by the turn of a handle.

HAYDEN-NILOS BELT REBUILDING SYSTEM

Then take the prepared pieces with their accurately-cut even edges and join them into a complete belt by the Hayden-Nilos Rebuilding Equipment. The result is a complete length of serviceable belting. This system has been a proved success in numerous collieries and other establishments. Write for full details and a demonstration.



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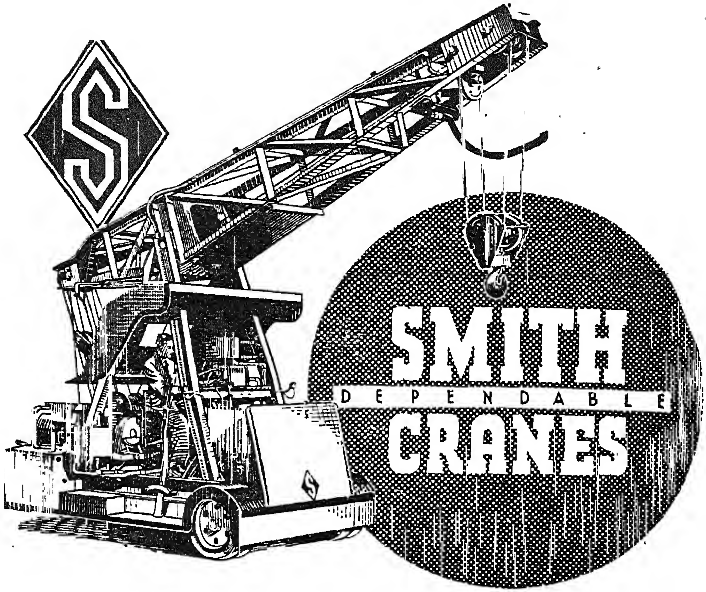

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Smiths build Cranes of all sizes and capacities, from the handy little 5-ton Diesel Electric runabout illustrated above, to a Large Radius Dockside Crane. Other types include: Steam Locomotive and Shunting Cranes with ordinary hooks, magnets or grabs; Steam Railway Breakdown Cranes; Diesel Mobile Cranes on road wheels or caterpillar tracks; Diesel Locomotive or Shunting Cranes; Diesel Electric Mobile Cranes; Electric Travelling Overhead Cranes; Electric Locomotive Cranes; Electric Level-luffing Dockside Cranes; Electric Screw Derrick Cranes; Electric Pulley Blocks and Capstans.

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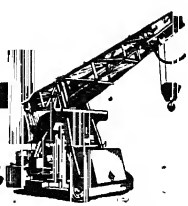

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Specialists in the design and manufacture of Cranes and Excavators

---

The instructions sent out with every HF vulcaniser enable any mechanic to carry out the work.

Design.—The design of the HF vulcanisers themselves is interesting. The have either one or two electrically heated platens fitted with "Chromalox" embedded strip heaters of high efficiency. Owing to their construction, sagging of the resisters is eliminated and shorts cannot occur. Temperature is maintained at correct vulcanising point by a bi-metal vacuum thermostat set during manufacture to the required operating temperature.

CRANES

Cranes are available in a wide variety of types, from hand cranes, suitable for loads up to 30 lb., to power-driven cranes capable of handling loads from a few tons up to hundreds of tons. Power cranes are either steam or electrically operated. The tendency nowadays is towards electric cranes, because power is not consumed whilst the crane is standing, they are immediately ready for use, are simple to operate, and the power used varies according to the load.

Hydraulic cranes may be advantageously used when they are to be kept working under full load. They are chiefly used in shipyards, as they have the advantage of small lifts at low speed. The hydraulic pressure employed is usually between 1500 and 5000 lb. per sq. in.

Cranes which are pneumatically operated (usually for only small loads) employ an air pressure of about 120 lb. per sq. in. Other types employ internal-combustion engines, of either the Diesel or petrol types.

Overhead Travelling Cranes.—A single-girder crane can safely be used for hand operation up to a load of 5 tons and 40-ft. span, and those of this type may be operated from the floor level by suspended chains.

Above loads of 10 tons a crane platform should be used. The electric overhead crane is ideal for foundries, steel works, and heavy duty generally.

Height of Lift for Cranes.—Details of warehouse cranes: Height of lift = net height bottom floor to top floor + 6 ft. Underside of jib head sheave 10 ft. 6 in. above level of top floor.

Details of coal cranes: Minimum height of lift on floating wharf = 40 ft. Height of lift at fixed jetty, 50 to 60 ft., depending upon the rise and fall of the tide and other circumstances. Height of lift to riverside hoppers, 60 to 80 ft. An extra lift of, say, 10 ft. is sometimes required to reach the coal tubs in corners of the hold.

Effective Pressure for Hydraulic Cranes and Hoists.—

$$E = p\,(0{\cdot}84 - 0{\cdot}02m)$$

Where p = Accumulator pressure in pounds per square inch.
m = Ratio of multiplying power.
E = Effective pressure in pounds per square inch, including all allowances for friction, but not for weight of moving parts.

Hydraulic lifts are usually balanced to three-quarters weight of car.

When working, the pressure varies from half to one and a half times the standing pressure, increasing to double at instant of stopping owing to momentum in pipes.

Counterweights for Crane Chains.—The overhauling weights should be oval, i.e. egg-shaped, with small end on top to avoid catching under beams, etc. Hole for chain should be ⅛ in. larger than cross section of links, and interior should be cored out to ⅛ in. clear all round. The approximate weight of counterbalance required is one-twentieth of the load.

STRESS ALLOWED ON WROUGHT IRON IN HYDRAULIC CRANES

Type of Crane.	*Tons per sq. in.*	
	Tension.	*Compression.*
(For mild steel add 50 per cent.)		
Ballast and coaling cranes	2½	1
Warehouse and other cranes lifting from 1 to 5 tons	3	2
Cranes lifting more than 5 tons	3½	3

Autogenous Welding.—Metals can be autogenously welded by bringing the molecules of the two parts to be joined in close relation to one another so that they come within each other's sphere of attraction, and the cohesion of the molecules can be further assisted by the application of heat. This is the basic principle of the joining of metals by thermal energy.

Metals are welded by one of two fundamentally different methods. In the first the material is heated to welding temperature (about 1650° F. for soft ingot iron), and by pressing the two parts to be welded firmly against each other the joint is made. This is the familiar forge or fire weld, and the resulting joint is known as a pressure or resistance weld.

In the second method the material is heated above the melting-temperature (about 2700° F. for soft ingot iron), and the joint is effected through the materials merging into each other without pressure. This is known as fusion welding.

Resistance or Pressure Welds.—The resistance which an electric current encounters when passing from one contact surface of the parts to be joined to the other produces the heat required for raising the material to welding temperature. This type of welding comprises *butt welds*, in which each of the two work-pieces is fixed in a clamp (Fig. 1), which is connected to the secondary side of the welding transformer. The surface of one piece to be welded is pressed against that of the other by means of the adjustable sliding clamp A. The current passes from one terminal through the work-pieces and back into the welding machine, and the resistance encountered at the joint generates heat that causes the two adjacent faces of the work-piece to become plastic. The pressure then causes the two pieces to make a homogeneous joint. For a *flash butt weld* the arrangement of the machine is the same as that for the butt weld; the current is switched on and the two parts are slowly brought together. When they make contact, arcing takes place and a shower of sparks emanates from the joint. When welding temperature has been reached, the two parts are pressed together and become fused, leaving a thin irregular fin which has been squeezed from the joint. This is known as the *upset*. The operation is timed and controlled by mechanical electrical devices to ensure continuity of weld efficiency. The flash butt weld is used for joining tubes, rods, sectional bars, and steel sheets, and the operation is limited only by the capacity rating of the machine.

Spot Welds.—Spot-welding machines are equipped with two electrodes (Fig. 2). The electrodes have a dual purpose—supply and return of current; whilst they also provide the necessary pressure during welding. The movable electrode A presses the two sections of sheeting against each other; a powerful current of low voltage passes through for a short period, which causes the two overlapping sheets to become plastic and thus fuse together; in this way the weld is produced. The passage of current is in most cases automatically timed, and when the pressure of the electrodes is released the job is moved along, and a further spot weld can be made in another place. Welding is effected with a voltage between the electrodes of 1–7 volts and with currents up to 30,000 amps. or more.

Seam Welds.—In seam-welding machines the rod-shaped electrodes are replaced by rollers, one or both of which are driven at a constant speed (Fig. 3). At frequent intervals current surges are applied and a chain of spot welds is produced. These spot welds partly overlap each other, so that a watertight joint is produced.

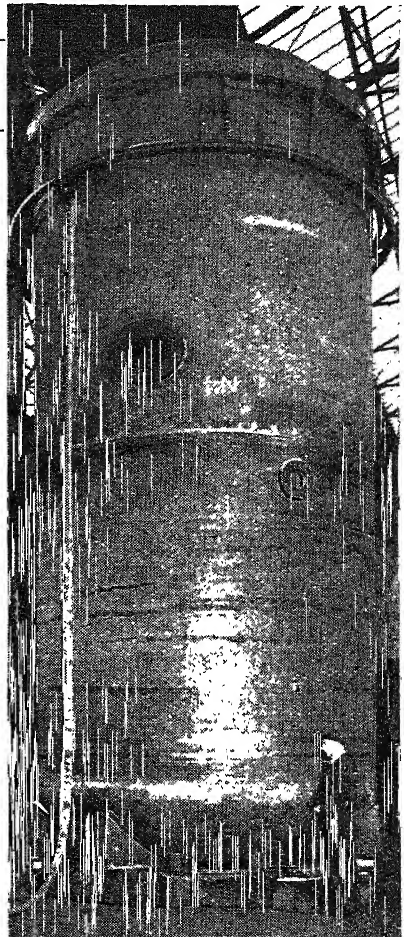
Fusion Welding.—In oxyacetylene and gas welding the heat required to bring the metals to a molten condition is supplied by the combustion of a fuel gas with oxygen. The gas normally used is acetylene. Whatever gas is used it is fed under pressure through a blow-pipe, which acts as a mixing chamber. Ignition then takes place to form the welding flame. Supplies of oxygen are obtained either from cylinders or from storage tanks, and acetylene either from cylinders (dissolved acetylene) or from acetylene generators.

Arc Welding.—The heat is produced by an electric arc (A in Fig. 4) which is drawn between the welding electrode E and the work-piece P. The electrode can be either a metallic rod or a carbon rod. The metallic rod, which may be bare wire or a metallic core which has a flux coating, melts down during welding

WELDING

Modern automatic welding equipment combined with microscopical, chemical and mechanical testing (both static and fatigue) and the rigid radiological inspection of every foot of welding, enables us to produce the highest quality of welded work in Mild Steel, Stainless Steel, Nickel, Nickel-Clad and Stainless-Clad to meet specifications of all grades including Lloyds Class I, Admiralty "Grade A," A.O.T.C. Class I, A.P.I. and A.S.M.E. Codes.

We specialise in Fabricated Industrial Plant of all kinds.



Welded Evaporator 11′ 0″ dia. 26′ 0″ long W.P. 250 lbs. Weight 50 tons to Lloyds Class I and A.S.M.E. Code.

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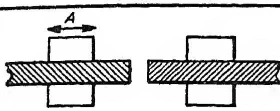


Fig. 1.—Resistance butt welding.

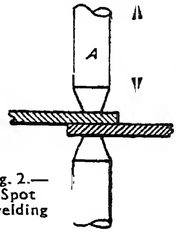


Fig. 2.—Spot welding

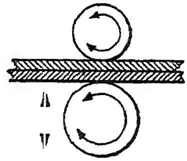


Fig. 3.—Seam welding.

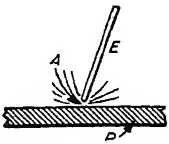


Fig. 4.—Arc welding.

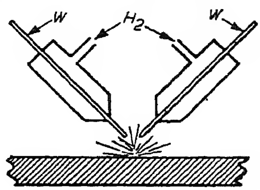


Fig. 5.—Atomic-hydrogen welding.

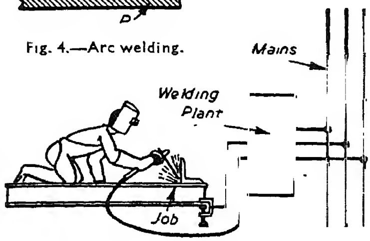


Fig. 6.—Principles of arc welding.

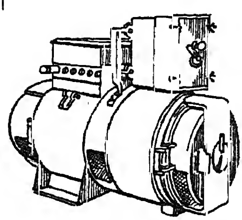


Fig. 7.—Typical example of a motor generator.

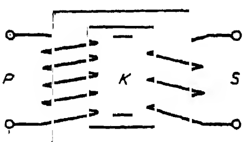


Fig. 8.—Principles of transformer design.

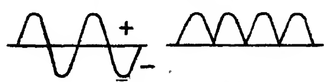


Fig. 11.—A.C. oscillogram.

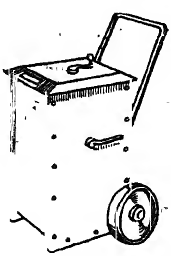


Fig. 9.—Welding transformer.

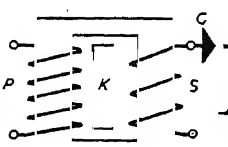


Fig. 10.—Principles of rectifier design.

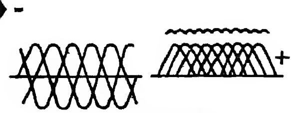


Fig. 12.—Pulsating direct current.

and provides the necessary filler for forming the welding seam. The carbon welding rod is primarily used for drawing the arc, but can be used with or without any filler metal, according to the type of joint to be welded. The carbon arc is of historic interest, because it provided the means for the invention of electric-arc welding. Although for many years it has been superseded for most purposes by the metallic arc, there are certain types of work for which it is used.

Atomic-hydrogen Welding.—In the arc, drawn between two tungsten electrodes (W), hydrogen molecules (H_2) are disintegrated (Fig. 5); the hydrogen atoms liberated combine on the work-piece into molecules and give off heat which is absorbed in the arc, causing the material of the work-piece (and that of the filler rod, if any, held close to it) to melt. The arc is thus enclosed in an envelope of hydrogen, which eliminates the absorption of oxygen and nitrogen in the resultant weld. Atomic hydrogen welding is an expensive method and so is very little used. It lends itself, however, to the fusion of most non-ferrous metals and gives a very sound finish to stainless steels.

Thermit Welding.—Briefly, the process of thermit (fusion) welding is one of chemical change or combination, and is brought about by the affinity of aluminium to oxygen. The heat is produced by a chemical reaction between aluminium and ferric oxide, which are placed in a crucible (around the joint to be welded) and ignited. The high temperature thus attained (about 5400° F.) causes the aluminium and oxygen to combine, and the molten iron is separated from the ferric oxide. The molten iron settles at the bottom of the crucible and combines or fuses with the metallic joint, whilst the slag floats to the top. This process is used widely for the jointing of rails and pipes, and is normally restricted to new installation work of this kind.

Thermit (pressure) welding is a pressure-welding process in which the heat is obtained from the liquid products of a thermit reaction.

Electric-arc Welding Equipment.—The equipment necessary for electric-arc welding comprises: (*a*) electrical plant to supply current and the correct voltage for the work in hand; (*b*) a supply of suitable welding electrodes; (*c*) welding cable, work-piece cable, electrode holder, gloves, mask or shield, and protective clothing.

Briefly, the technique of the process is as follows:

The holder in which the electrode is fixed is connected by means of a welding cable to one of the output terminals of the welding apparatus, the work-piece being connected to the other output terminal by means of the work cable (Fig. 6). When the work-piece is touched with the point of the electrode, the output circuit of the welder is closed and no current can pass (short-circuit voltage = 0 volt). The moment the electrode is moved away from the work-piece, the arc is "struck." The point of the electrode can then be held a certain distance, from $\frac{3}{32}$ in. to $\frac{3}{16}$ in., away from the work-piece, and the arc continues burning in the intervening space, which has become conductive as a result of ionisation (temperature of arc about 6500° F.). The heat generated in the arc raises the electrode material and the affected part of the work-piece to a molten state, whereupon the molten electrode globules flow across to the crater or molten bath formed in the work-piece, and on congealing form the welded joint.

Welding Plant.—For welding it is essential that the current shall comply with certain requirements, viz.:

(*a*) In order to strike the arc a certain starting voltage must be available, e.g. 70 volts (open-circuit voltage of welding apparatus). (*b*) The voltage during welding should be about 25 (welding voltage). (*c*) On short-circuiting the point of the electrode with the work-piece, during which the electrical resistance, and hence the voltage, drops almost to nil, the current (short-circuit current) must not increase unduly.

The usual source of supply is from the power company's mains, and as the supply voltages vary from 190 to 500, it is necessary to reduce this to the pressure mentioned in the previous paragraph. This can be accomplished by means of electrical welding apparatus which, when connected to the mains, gives the desired output.

There are three principal types of welding plant in use:

The Motor Generator (Fig. 7): This consists of an electric motor connected to the mains—driving the welding dynamo, which supplies direct current at the

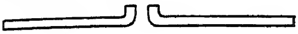
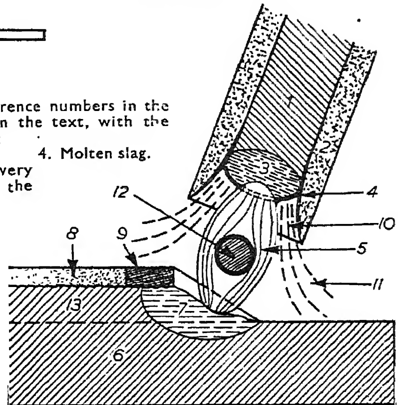


Fig. 13.

Fig. 13a (*Right*).—The reference numbers in the diagram are referred to in the text, with the exception of the following:
3. Molten metal drop. 4. Molten slag.
10. Cup, which has a very favourable influence on the stability of the arc.



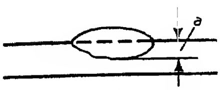


Fig. 14.—Showing depth of penetration.

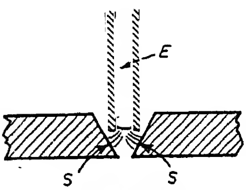


Fig. 15.—Effect of electrode diameter on penetration.

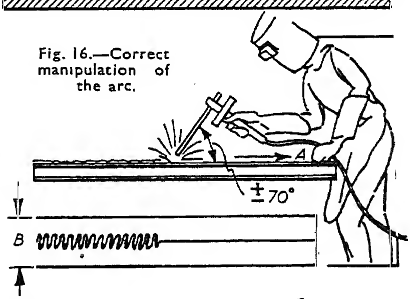


Fig. 16.—Correct manipulation of the arc.

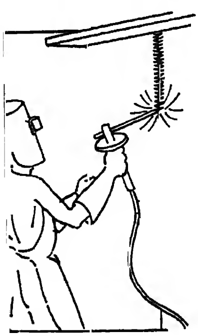


Fig. 17.—Vertical downhand welding.

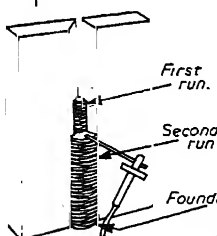


Fig. 18.—Showing ledge upon which to build metal.

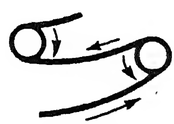


Fig. 18a.—Movement of electrode.

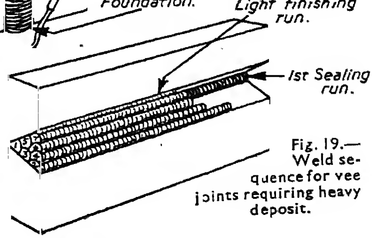


Fig. 19.—Weld sequence for vee joints requiring heavy deposit.

required voltage. Instead of using an electric motor it is also possible to supply motive power by mechanical means, i.e. a petrol or Diesel engine may be connected to the dynamo.

The Transformer (Fig. 8) *:* Consisting fundamentally of primary windings (P), surrounding a fixed core; around this core are the secondary windings (S). When alternating current from the mains passes through these primary windings, it sets up a magnetic field (lines of force) in the core. This magnetic field induces an alternating voltage in the secondary windings; on shorting the secondary circuit (welding), a current flow is thus set up in these windings (welding current). By leading off a portion of the magnetic field, thus weakening the field in the secondary windings, the voltage is reduced, and, as a result of this, the current also. Hence the strength of the welding current can be adjusted by slipping a movable core (K) in or out. A transformer having an adjustable core for regulating the output current is called a leakage transformer.

Another way of controlling the current strength is to take or tap current from different points on the secondary windings (the tapping transformer). The cores are built up from thin, mutually insulated, sheets of iron, known as laminations. The transformer is connected to one phase of the mains, i.e. coupled between two wires of the three-phase supply, and supplies alternating current from its secondary windings for welding. Fig. 9 shows a welding transformer.

The Rectifier (Fig. 10) *:* Comprises two parts. One part is a transformer which does not deliver current direct to the secondary terminals but to another part (G) which rectifies the alternating current. This rectification consists in allowing electrons to pass in one direction only, which means in the A.C. oscillogram (Fig. 11) the cutting-off of all that occurs below the time-line. By means of a special circuit the current component that is cut off below the time-line can be reversed and passed on as a positive value. Moreover, not only one phase but all three phases of the three-phase mains can be rectified in this way. Therefore, when connected to the three phases of the mains, the welding rectifier supplies pulsating direct current for welding purposes (Fig. 12). There are certain types of welding rectifiers which normally supply direct current, but which, by disconnecting the rectifier section, can also supply alternating current. These are known as *dual-current welding plant.* Whilst, as a rule, a welding plant supplies welding current for use by one welder, equipment is also available which supplies several welding-points at the same time. In this case every welder has a control resistance (for D.C. welding) or a control choke (for A.C.), enabling him to adjust the welding current as required.

Welding Electrodes.—As we have already seen, in arc welding the arc is drawn between a rod and the work-piece. This rod may be of carbon, known as the carbon-electrode, or of metal, known as the welding electrode or metallic electrode.

The carbon electrode is either a solid carbon rod or one which consists of two kinds of carbon, i.e. a jacket with a core of harder carbon. The thickness of the carbon rod (for instance, $\frac{3}{16}$ in. or $\frac{1}{4}$ in.) depends on the required current strength, and is therefore also dependent on the thickness of the material to be welded. During welding the carbon rod does not melt, but loses a slight quantity of carbon material, which passes partially into the molten parent metal. The material for making a full weld may be supplied by the work-piece itself (for instance, "leaf edges," Fig. 13), or must be added by means of a separate filler rod, as is done in the case of gas welding.

A weld made with a carbon electrode is porous and brittle, due primarily to the effect of the oxygen and nitrogen in the atmosphere, which rapidly attack the metal whilst molten and combine with it to form what are known as iron-oxides and nitrides of iron. Were we to examine the affected area under a microscope a definite crystalline structure would be seen in the fusion area, whilst visual inspection only would reveal porosity. Another disadvantage is the high current necessary to raise the job to the required heat (approximately twice that necessary for metallic-arc welding), together with the fact that, as in gas welding, much of the heat is lost, due to the deflection of the arc itself from the actual welding-point.

The carbon electrode must be connected to the negative pole of a D.C. supply in order to make a successful weld; if connected to the positive terminal, approximately two-thirds of the heat developed would be in the electrode, and con-

Fig. 20.—Overhead welding.

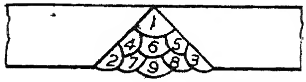


Fig. 21.—Method of welding an overhead vee.

Fig. 22.—Making a lap weld.

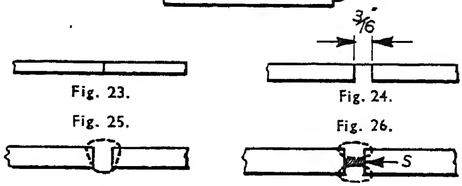


Fig. 23. Fig. 24.

Fig. 25. Fig. 26.

Figs. 23-26.—Square butt joints.

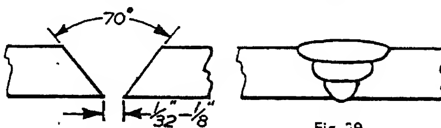


Fig. 28. Fig. 29.

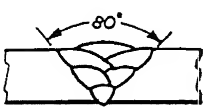


Fig. 27.

Figs. 27-29.—Single-V butt weld.

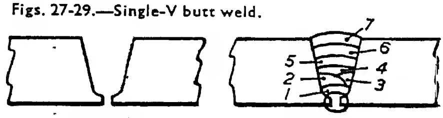


Fig. 33. Fig. 34.

Figs. 33-34.—Weld sequence for single-U butt weld.

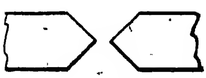


Fig. 30.

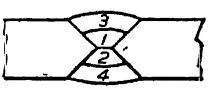


Fig. 31.

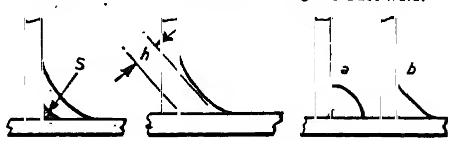


Fig. 36. Fig. 37. Fig. 38.

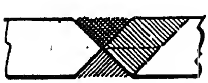


Fig.32.

Figs. 30-32.—Double-V butt weld.

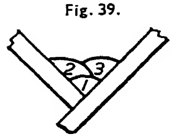


Fig. 39.

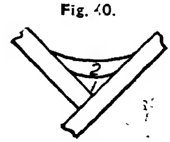


Fig. 40.

Figs. 36-40.—Fillet welding technique.

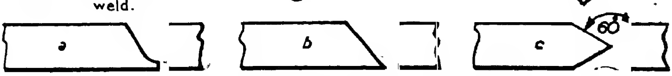


Fig. 35.—(a) The single-J butt weld; (b) the single-bevel butt weld; (c) the double-bevel butt weld.

sequently the latter would rapidly burn away and the excessive carbon would be segregated from the electrode and find its way into the metal, thus giving a weld which would be very hard and brittle. For the same reason carbon electrodes cannot be used with A.C., because during half the period of the welding operation the carbon would be positive.

Metal welding electrodes can be divided into two groups, viz. (*a*) bare wire (electrodes producing no slag); (*b*) coated electrodes (slag-producing electrodes).

(*a*) Bare wire usually consists of ordinary Swedish iron wire, but this depends on the properties and character of the parent metal. Bare wire, like the carbon-electrode, cannot be welded with A.C., but must be connected to the negative pole of D.C. welding units. For bare-wire welding the voltage amounts to 18–24 volts, according to the size of wire and job.

In comparison with welds made with flux-coated electrodes, those made with bare wire or with carbon rods are poor in quality and unreliable, and therefore the process is uneconomic.

(*b*) Coated electrodes (Fig. 13a) are metal rods (1) around which a coating of certain materials (2) is applied in various ways, and the phenomena which occur during welding are described below.

During welding, the coating melts down simultaneously with the metal core and surrounds the metal dripping from the core (12). It is then deposited as a uniform layer of slag (8, 9) on the weld deposit (13). (6) is the work-piece and (7) the molten bath or crater. According to the manner in which the coating is applied, the electrodes are divided into dipped, extruded, and wrapped or wound electrodes, in the latter the winding being of asbestos or cotton yarn. The composition of the coating may consist of inorganic materials, such as silicates, iron ores, etc., or organic materials, such as starch, sawdust, etc., though the coating of some types of electrode may consist half of organic materials and half of inorganic materials. The organic coating burns away, with the advantage that the combustible gases (11) enclose the arc (5), and in this way form, next to the insulating layer, an insulating gas layer which prevents the harmful influences of the gas in the air. The organic coating is characterised by a pungent odour during welding. As a rule, coated electrodes can be used on either D.C. or A.C., but when using D.C. the prescribed polarity must be adhered to. The welding voltage amounts to 20–30 volts, dependent on the thickness and the composition of the coating.

Functions of the Coating.—Manufacturers of electrodes—the essential part of which is steel or other metal—coat them to perform the following functions:

(*a*) Prevents the occurrence of metal oxides and nitrides through contamination of the weld metal with the oxygen and nitrogen in the air. Oxides make the weld porous and prevent homogeneity; nitrides (hard and brittle nitride needles) reduce the ductility and the tenacity of the weld metal.

(*b*) Compensates for the loss of certain elements (e.g. carbon, manganese, or chromium) of the welding material through combustion, by combining them in the coating.

(*c*) Anneals the weld by the prevention of rapid chilling so that a homogeneous and fine structure is obtained.

(*d*) Gives the weld special properties through the addition of chemicals to the coating.

(*e*) Influences welding characteristics (outward appearance of the bead, fusing speed, etc.).

(*f*) Stabilises and more or less directs the arc, in order that the arc can be maintained more easily when welding with A.C.

(*g*) Acts as a melting agent by making the metal more mobile.

Coated electrodes must fulfil the following requirements:

(*a*) The coating must melt regularly and simultaneously with the metal core.

(*b*) The slag must have a lighter specific weight than the molten metal in order that it shall float readily to the surface and thereby eliminate slag inclusions in the weld.

(*c*) The slag must cover the welding bead with a uniform layer; accumulations of slag tend to detract from the uniformity of the weld.

(*d*) Upon the weld cooling down, the slag must be easily removable.

Three Main Electrode Groups.—It is obvious that, according to the com-

position of material to be welded and the mechanical properties desired in the finished work, so will a suitable type of electrode be necessary. It is convenient to classify electrodes into three main groups, as follows:

Group 1: Electrodes for making joints in iron and steel. The various types that belong to this group can be classified according to their mechanical characteristics (mainly tensile strength and elongation) and their welding characteristics.

Group 2: Electrodes for making hard surfaces having a high resistance to wear (abrasion and friction). Classification of the types—according to the hardness of the welding material deposited.

Group 3: Electrodes for welding special metals, such as aluminium, bronze, stainless steel, etc.

Where no heavy demands as to ultimate strength are made on the welding material, thinly coated electrodes may be used whose characteristics do not differ considerably from the bare wire, except that some flux coating is necessary, however slight, in order to permit welding with A.C. A heavily coated steel electrode can be used for almost all welding operations and particularly where high demands are made on the work. The coating of some electrodes is of such a composition that the welding material becomes very liquid, and combined with this feature the coating is current-insulating, so that during welding it may touch the work-piece without risk of freezing and without extinguishing the arc; these electrodes are called "touch welding" electrodes. The mechanical properties of a weld made with this type of electrode are, as a rule, not so high as might be obtained with a thicker coating, because the weld, being concave, has less throat depth—a condition which is most undesirable in any strength weld, but the outward appearance of the weld is very regular and finely marked.

All electrodes are made in varying gauges and lengths (the thickness or gauge of an electrode is the cross-section of the metallic core) suitable for use with the many different thicknesses of metal to be welded, and the amount of current the electrode has to pass. For instance, a 16 S.W.G. rod and current strength of 20 to 30 amps. would be necessary for welding 18-gauge sheet metal, whereas ½-in. plate would need at least an 8 S.W.G. rod and 150 amps., according to the nature of the joint. A good weld can be obtained only if the correct current and electrode are chosen, and if the electrode, parent metal, and slag fuse in correct relation to each other.

The following table provides a useful guide as to thickness and length of electrode and the relative current strengths for welding steel with various gauges of electrode.

TABLE I

Thickness of Electrode, S.W.G.	*Length in Inches*	*Current (Strength) in Amperes (very approximately)*
20	10	8– 15
16	10	12– 35
14	14	30– 70
12	16	50–100
10	18	75–140
8	18	100–180
6	18	130–235
4	18	150–285
2	18	180–330
0	18	210–405
⅜ in.	18	260–480
½ ,,	18	300–550

There is another type of electrode infrequently used which is not coated and yet belongs to the class of slag-producing products, viz. the cored electrode. With this type the slag-producing substances are not in the form of a coating, but fill

the tubular metallic casing. The characteristics of cored electrodes can be compared with thinly- or medium-coated electrodes.

Accessory Equipment (Cables, Electrode Holders, Screens and Masks, Protective Clothing).—Cables designed to pass the peak current value are normally supplied with an electric-arc welding plant.

Electrode holders are made in several designs, some with an automatic device for lowering the point of an electrode as it is used, but the student is recommended to choose the type which best suits him after practical experiment.

To ensure weld efficiency, it is of primary importance for the connections to the welding machine to be electrically perfect, and to use a holder having a minimum of joints. Periodic cleaning of all contact points must be done regularly.

Screens and masks are a most important part of a welder's equipment. There has been much research work in recent years in regard to the colour, thickness, and density of the glass through which the welder surveys his work. Again, experiment will soon demonstrate the colour which best suits the individual operator, and it is scarcely necessary to add that it is dangerously uneconomic to employ any article but the best obtainable for the protection of the eyes from the fierce rays of the arc. As the electric arc when struck throws up sparks of molten metal continuously, gloves or gauntlets and overalls should always be worn, and for this reason the mask which protects the head and hair, as well as the eyes, is preferable to the hand screen, especially for lengthy periods of work.

Welding Practice.—Before beginning the actual operation of welding two pieces of metal together, the student must understand something of the quality of work at which he is aiming. Almost anyone can use an electric welding plant for the first time, and make some kind of joint—but it is extremely unlikely that he will make a sound weld at the first attempt. The object of all the care and thought and practical skill put into welding is to ensure *thorough penetration*, without which no sound weld can be made. The student should therefore make himself well acquainted with the following remarks on this subject before taking up his electrode holder and striking his first arc.

Penetration may be defined as the depth of the zone of fusion which occurs in the parent metal during welding. The weld material mixes with the parent metal, and after congealing this mixture forms the weld.

The depth of penetration (Fig. 14) is the thickness of the fusion layer or depth of the crater formed by the arc. One of the most important demands that can be made on a weld is sound adhesion of the weld metal to the work-piece, which can be obtained by closely mixing the two materials whilst in the molten condition. Therefore, the welder must watch carefully the condition of the molten bath, the fusing of the electrode metal, and the flow of the slag. If one of these three factors is not in order, it is probably due to one or both of the following:

(*a*) The current has not been suitably adjusted, and/or (*b*) the wrong thickness of electrode is being used.

We know that the heat applied to the work-piece must serve to melt the material; however, part of it is lost, due to the rapid heat dissipation by the cold work-piece. The thicker the work-piece the more heat is lost and the less remains available for forming the crater. Therefore, if the welder notices that the size of the crater is too small, the current must be increased. Every thickness of electrode can carry a limited maximum current. If the crater is still insufficient when applying this maximum current, a thicker electrode must be selected in order to obtain better penetration. Conversely, when thin material is being welded, little heat is absorbed by the cold base metal. If in this case welding were to be effected with relatively thick electrodes, too much heat would be applied to the formation of a crater, so that the latter would become too large, and there would be considerable risk of holes being burnt into the base material. Less heat must therefore be applied; in other words, the current must be reduced. But if the current is insufficient, the weld metal and the slag of thickly coated electrodes will freeze rapidly and give rise to impedance due to poor flow, and for this reason thin material must be welded with thin rods.

The welding current and the thickness of the electrodes are thus of primary importance, and must therefore be chosen as accurately as possible in order to obtain correct flow of the weld metal and the work-piece.

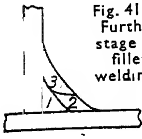


Fig. 41.—Further stage in fillet welding.

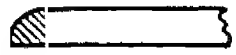


Fig. 42.—Corner weld.

Fig. 42a.—Lap weld.

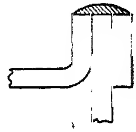


Fig. 44.—Edge joint.

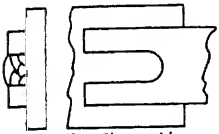


Fig. 43.—Slot weld.

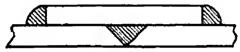


Fig. 44a.—Butt strap joint.

Fig. 45.—Tensile stresses.

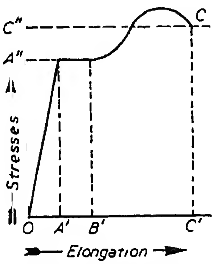


Fig. 46.—Diagram showing stress elongation.

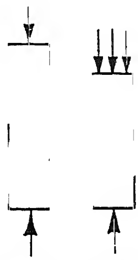


Fig. 47.—Compressive forces.

Fig. 48.—Effect of heat on iron bar.

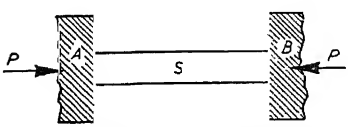


Fig. 49.—Diagram illustrating clamps preventing expansion of bar S.

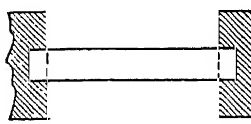


Fig. 50.—Another method of clamping the bar.

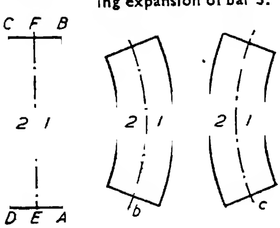


Fig. 51.—Diagrams illustrating thermocouple and plastic shrinkage.

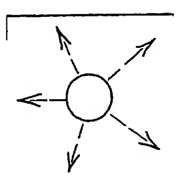


Fig. 52.—Diagram showing plate heated at centre.

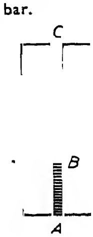


Fig. 53.—Two plates seam welded.

The average values mentioned in Table II can be taken as a guide for downhand welding of wrought iron and mild steel :

TABLE II

Thickness of Material, S.W.G.	*Diameter of Electrode, S.W.G.*	*Current (Strength) in Amperes*
24–20 gauge	20	8– 12
16 ,,	16	15– 35
14–10 ,,	14	30– 70
10– 0 ,,	10	75–140
$\frac{1}{4}$–$\frac{1}{2}$ in.	8	100–180
$\frac{3}{8}$–$\frac{3}{4}$,,	6	130–235
$\frac{3}{4}$–1 ,,	4–2	150–285

When making a joint between thick materials, the preparation of the joint area and selection of electrodes should be such that effective penetration is ensured, and in no circumstances should the electrode diameter be of such a magnitude as not to allow penetration into the root of the joint (Fig. 15). The arc takes the line of least resistance, and therefore the shortest path between the point of the electrode (E) and the surface of the work-piece (S). At the root of the weld a thick electrode will therefore not be able to produce penetration, and so no adhesion of the weld metal will occur ; in such cases the first run will have to be made with relatively thin electrodes.

Manipulation of the Arc.—Having decided upon the correct diameter of electrode and the proper current strength in accordance with the thickness of the material upon which he is to work, and having adjusted his plant to supply that current strength and placed his cable in position, the student proceeds to strike his arc and begin welding.

Striking the Arc.—The easiest way to strike an arc is by brushing the point of the electrode over the work-piece just as when striking a match, and then gradually drawing the electrode away, or by striking the point of the electrode as a bird pecks at a seed. Once obtained, the arc may be held continuously by holding the electrode approximately $\frac{3}{32}$ in. from the work-piece. At first this may be difficult, but proficiency will soon be obtained with practice.

Correct Arc Length.—A good short arc is essential for sound welding, and once obtained must remain constant. Upon the arc being struck electrode metal flows across to the work-piece so that the rod gets shorter, hence it follows that the electrode holder must be moved towards the work-piece at a speed corresponding to the flow of the electrode metal.

It is not possible to detect the correct arc length by means of the naked eye (usually it comes to the welder by experience), but there are at least three methods of determining its correctness :

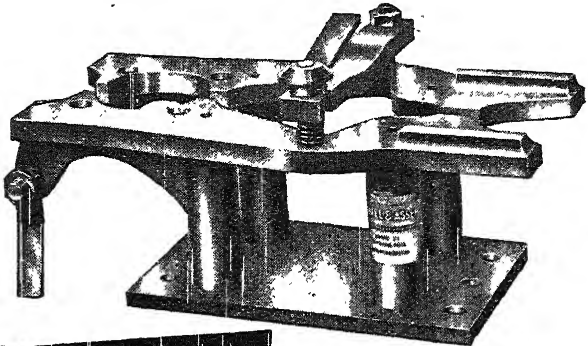
(*a*) A good short arc will give off a decided crackling sound, and a long or bad arc will only " hiss."

(*b*) With a short arc there is a small flame or " halo " completely enveloping the arc itself, but with a long arc there is a correspondingly long flame which whirls round the electrode, exposing first one side and then the other to the atmosphere.

(*c*) The transfer of molten metal from electrode to work should never be visible to the naked eye ; with a long arc this can be clearly seen, but with a short arc only the deposit following the electrode is noticeable.

Progressive Movement.—To make a welding bead of a certain length, the electrode must be moved in the direction of welding (A in Fig. 16). The progressive movement (speed of progression) depends on the section of the bead to be made and on the degree of fusing of the type of electrode used.

Weaving.—In order to make a wide welding bead, the point of the welding rod must be moved to and fro at right angles with the direction of welding (B in



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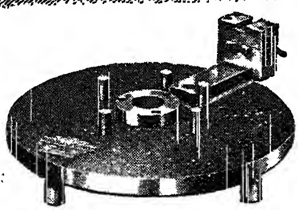

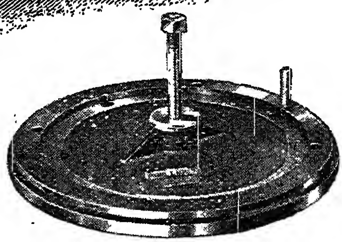

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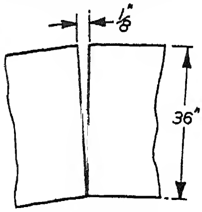


Fig. 54.—Plates placed so that end closely abuts.

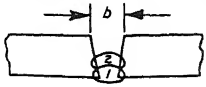


Fig 55.—Congealing and cooling effects.

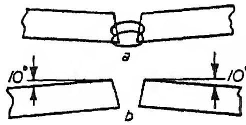


Fig. 56.—(a) Shrinkage distortion. (b) Method of offsetting distortion.

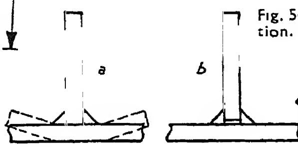


Fig. 57.—(a) Distortion transversely to weld. (b) Small gap partly prevents distortion.

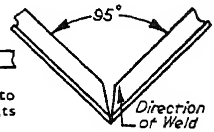


Fig. 59.—Preparation for corner weld.

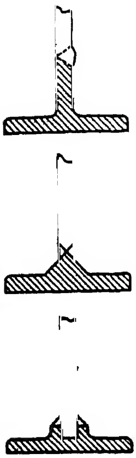


Fig. 58.—Special welding sections.

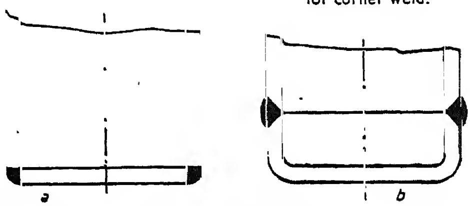


Fig. 60.—Butt weld (b) produces less distortion than (a).

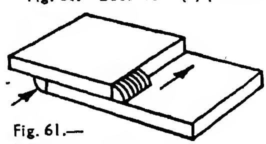
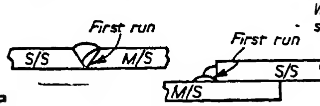


Fig. 61.—Direction of weld.

Fig. 62.—Obviating stress concentration.



Figs. 64-65.—Welding stainless to mild steel.

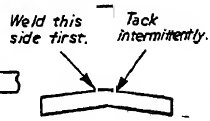


Fig. 63.—Fillet welds.

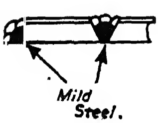


Fig. 66.—Welding stainless clad steel.

Fig. 67 (Above).—Mild-steel bar welded.

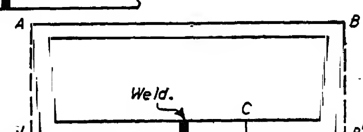


Fig. 68 (Right).—Distortion of framework.

Fig. 16). The width of the oscillating movement determines the width of the welding seam. The maximum width of welding seam is four to five times the thickness of the electrode.

If during welding there is no weaving and the electrode is manipulated only with a downward and progressive movement, a simple bead is produced; this is therefore the narrowest form of weld.

Neatness of appearance and uniform penetration throughout the weld depend as much upon arc manipulation as on the selection of rod and correct current values, so that the movements must be carried out regularly and with due care.

Welding Positions.—According to the position of the seam to be welded and the side on which the weld has to be made (on top or underneath), welding is known as one or other of the following:

(*a*) Downhand welding.
(*b*) Vertical welding (downhand, uphand, or horizontal).
(*c*) Overhead welding.

Downhand Welding.—Welding is called *downhand* when the weld has to be made in a horizontal or a very slightly inclined plane, and is so made that the work-piece constitutes the base. In downhand welding, the inclination of the electrode should, as a rule, be at an angle of 70 degrees with the welding direction. At this angle the arc forces the mobile slag against the welding bead, and the crater will be kept as free as possible from slag inclusion.

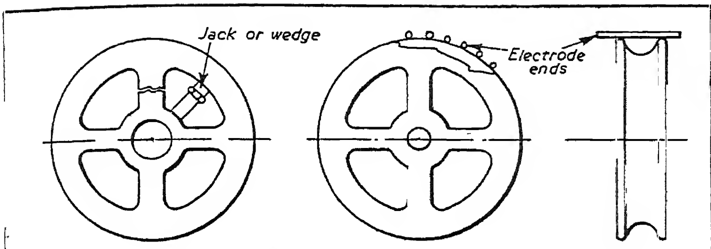
Vertical Welding.—A vertical weld is one with its linear direction inclined at any angle from 40 to 90 degrees with the horizontal plane, and although it appears difficult to the beginner, it should present no real difficulty, after some practice, if care and attention are exercised. The most important points to remember are accurate setting of the current, selection of the correct gauge of electrode, and uniformity in weld procedure. The electrode should be held at an angle of 75 degrees from the horizontal (although in some cases this may be varied), and a relatively short arc maintained by the operator; if we examine the behaviour of metal transference during the welding process, many simple mistakes may be avoided.

Vertical Welding (Downhand).—With this method of welding the following phenomena will be observed: immediately the arc is struck a small molten pool is formed in the parent metal, which readily receives the molten globules formed at the tip of the electrode; this continues until a greater area is in a molten condition, the tendency thereafter being for the pool to widen out and finally collapse. This, of course, is due to gravitation acting upon the liquid surface and in order to rectify it we have at our disposal two opposite forces, i.e. surface tension and cohesion, both of which depend on the correct manipulation of the rod and a short arc. Surface tension causes the molten metal to squeeze itself into the smallest possible space upon freezing, and since the action of cohesion will be known it will readily be seen that the control of the arc should be such that the base metal and the electrode get sufficient heat to melt, but that the deposit should freeze fairly rapidly. Should the electrode be held in the same position too long, there will be a tendency for the slag which is more mobile to impede the progress of welding by dropping below the weld metal, and thus forming slag traps; the slag may also interfere with the operator's vision of the progress of the weld.

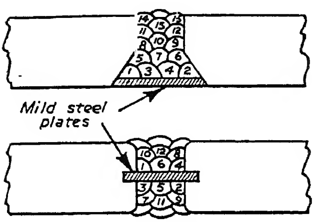
The first weld should be such that the metal has penetrated to the root of the joint, whether butt or fillet, and, in order to ensure this, the current should be a little higher than for normal flat welding, and the electrode controlled without any lateral movement. Subsequent runs can be carried out with slightly lower current and normal weaving on the electrode (Fig. 17). Great care should be taken when cleaning the first run, in order to reveal possible slag traps, for if these are allowed to remain they will not only impede the progress of any subsequent runs but will also seriously jeopardise the ultimate strength of the joint.

Whilst vertical downhand welding can be practised on all types of work, it is generally recommended that its use should be limited to sheet metal, thin plate, and work in which strength is not of primary importance. For work in which strength is essential, however, such as welding of pressure vessels and structural steel work, uphand vertical welding alone should be used.

Vertical Welding (Uphand).—In this case, the current should be slightly



Figs. 69 and 70.—Methods of welding two types of fracture in cast-iron pulley.



Figs. 71 and 72.—Method of preparation of weld sequence.

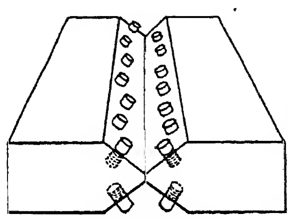


Fig. 73.—Method of studding.

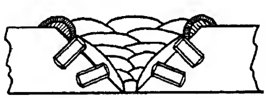


Fig. 74.—Weld sequence after studding.

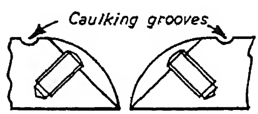


Fig. 75.—Reinforced layers deposited in caulking grooves.

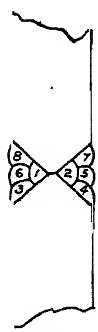


Fig. 76.—Vertical weld sequence in cast-iron repair.

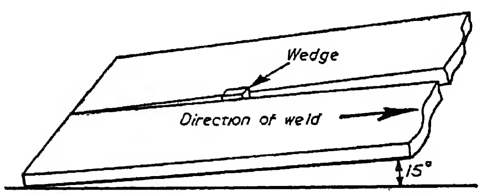


Fig. 77.—Wedges prevent too rapid closing of gap.

lower than that for horizontal welding (usually about 10 amps. less for No. 10 S.W.G. electrode), but here again root penetration must be the main objective with the first run. Subsequent runs can be made either by adopting the overlapping process (small beads knitted together) or by weaving. In the latter case the aim should be to form a ledge or foundation upon which to build the metal (Fig. 18). One of the evils met with in vertical uphand welding is "undercut," but in every case this can be overcome by correct control. "Undercut" may be due to the operator withdrawing the arc from the sides of the weld before drop formation has occurred, or, on the other hand, by his remaining too long at one point. To overcome this liability to undercut, the electrode should be allowed to oscillate from side to side in a half-moon formation, with a slight circular movement at each extremity (Fig. 18a).

Vertical Welding (Horizontal).—When welding in a vertical (horizontal) position, undercut of the top portion of the plate is more difficult to overcome, and it usually becomes necessary to add a further bead of metal—which should be done with slightly lower current but with increased speed, in order to deposit the minimum of metal.

Overhead Welding (Fig. 20).—The term *overhead welding* is used when weld metal is deposited on the underside of the work-piece, and although much skill is required in the transference of metal in an overhead direction, continued practice will surmount the difficulties usually met with by the inexperienced.

The transfer of metal in an overhead position is accomplished by the welder so manipulating the electrode as to overcome the force of gravity which naturally has a tendency to pull the molten metal away from the joint. This can best be achieved by holding a very close arc (combined with the correct current value) and by feeding the electrode towards the joint without any lateral movement. As soon as the arc is struck, a small globule of molten metal comes into contact with the work-piece. This spreads and unites with the liquefied work-piece, and if held in the same position will eventually sag as gravitation overcomes cohesion of the molten surface. If the electrode is moved along at a uniform rate, then the weld metal will chill fairly rapidly so that the gravitation overcomes cohesion.

Excessive oscillation or weaving of the electrode should not be practised unless the welder has full control over the liquid metal, and even then much better and speedier results will be obtained if the weld is built up by a series of narrow superimposed beads.

General Hints on Overhead Welding.—The maximum voltage obtainable from the welding machine should be used for overhead welding, as the tendency for the molten globule to hold to the work-piece is greatest when the voltage is high. Each successive bead of weld metal should be well chipped and brushed because the succeeding bead will be more difficult to deposit where it comes into contact with slag.

The welder should make himself comfortable, i.e. support himself to avoid swaying, and on no account resort to fast working or endeavour to make a large deposit with an oversize electrode.

For vertical and overhead welding, it is advisable not to use heavier gauges of electrodes than 10 S.W.G. or 8 S.W.G., so that the molten surface will always be under control; when using heavier electrodes a greater area of metal is melted, which will cause irregularity of weld surface and possibly total collapse.

Method of Welding an Overhead Vee.—The first bead should be deposited directly into the root of the joint, and then successive beads made on each side of the vee to form a base or foundation for further deposits (Fig. 21). Another method specially suitable for reinforcing is to support a copper bar along the extreme edges where metal is required, and to manipulate the rod as though it was intended to make a lap weld, as in Fig. 22.

Although excellent work is being done in vertical and overhead welding, downhand welding is to be preferred wherever it is possible to use this method, because in comparison with the other welding positions it has the following advantages: it is less fatiguing; better control is obtained over the molten weld metal and slag, so that the appearance of the weld is improved and there is less risk of slag inclusions; little or no loss of weld metal is incurred through dripping and splashing; penetration is more easily obtained; and the speed of welding is greater.

Automatic Welding.—A process capable of being accurately controlled in all its phases and able to produce a welded joint of uniform high quality.

For many years a great deal of welding research has been devoted towards the protection of the deposited weld metal from contamination by the atmosphere, resulting in the evolution of the coated electrode, which provides a protective gaseous shield around the arc.

Unionmelt Process.—One of the outstanding achievements in automatic welding has been the Unionmelt process, in which an uncoated welding rod is employed in conjunction with a special powder. The latter forms a flux permitting the use of high welding currents without loss of stability, resulting in high welding speeds and deep penetration of the metal on either side of the weld. The composition of this powder not only has the effect of controlling welding and other conditions, but it may also be used for introducing alloying elements into the deposited weld metal. The fused powder forms a slag resembling green bottle glass, which prevents radiation from the hot metal, thereby reducing considerably the quenching effect of the cold metal on either side of the joint.

Unionmelt powder is produced artificially in an electric furnace, being a calcium-magnesium-silicate compound, in which electrical conductivity increases with rise of temperature. Granular and free-flowing, it is deposited around the welding rod during the welding operation to a depth adequate to cover the end of the rod and to submerge the arc. No light is visible, and the danger of " arc eye " is thus eliminated.

A temperature of between 2000° and 2500° C. is attained in the welding zone, and the Unionmelt machine consists essentially of a motor-driven welding head feeding bare wire through straightening rollers into the weld, the Unionmelt powder being fed through a small hopper on the welding head; the entire machine is propelled by a sturdy built-in motor. The largest machine is of stationary type and handles rod up to $\frac{1}{2}$-in. diameter; it is capable of welding a maximum thickness of $2\frac{1}{2}$ in. of steel plate in one pass, with a maximum welding current of 3500 amps. In the smaller self-propelled machine, the welding head has been designed to deal with rod varying in diameter from $\frac{1}{16}$ in. to $\frac{5}{16}$ in.; the carriage is a robust unit carrying a built-in driving motor and equipped with an auto-guiding device. Voltage control is by electronic means, and ensures that a weld of excellent quality can be obtained by controlling the arc voltage within very close limits.

Although this system has found its main field of application in shipbuilding, it has also been employed in Canada and the United States for the welding of heavy ships' anchor chains; for fabricating large-diameter penstocks of hydro-electric installations; for welding pressure vessels, and for heavy structural work. In America the frames for Diesel locomotives have been automatically welded by this process in plates up to 4 in. thick.

It is in quantity production with resistance welding machines that automatic welding finds its widest range of employment. Here the use of the electron valve as a controlling device has enabled many alloys and metals to be welded rapidly and easily. Resistance welding may be spot, projection, seam, butt, and flash welding; electronic control is particularly suitable for spot, projection, and seam welding.

Automatic machines are typified by those made by the British Thomson-Houston Co. Ltd.; they are either mechanically or air operated. In the former a camshaft may be used, and electrode pressure is provided by the compression of a spring; an improved type of apparatus employs a mechanical toggle in conjunction with an air-operated cylinder. Electrode pressure can be varied by means of a reducing valve.

In the compressed-air machine the top electrode is controlled by an electrically operated air valve, a method becoming increasingly popular owing to the simplicity of the mechanical parts, and to the ease with which electrode pressure can be varied.

For the welding of aluminium alloys the " programme " form of spot welding is used; here the welding period is followed by a period in which the current is reduced to about 30 per cent. of that needed to make the weld. This current serves to anneal the weld by retarding its cooling.

For the welding of high-tensile and similar alloys, the "sequence programme" method is employed; here a predetermined intermediate "cool period" is inserted between the end of the welding period and the start of the post-weld heating period.

Woodpecker Welding.—Another form of automatic welding is known as "woodpecker" welding, in which the electrodes are brought together on the work and the current applied in pulsations, interspersed with periods of cooling. In continuous spot welding, a succession of overlapping spot welds is made in the form of a seam; this is sometimes termed "stitch" welding. Projection welding is another type of spot welding in which current flow is confined to certain areas of the work by means of projections raised on one or both of the parts to be welded.

There are many ingenious types of electronic control equipments available for these automatic welders. In general, an electronic device controls accurately the duration of current flow during welding periods of both spot- and projection-welding machines. Current is switched on and off by means of an electro-magnetic contactor or an electron-valve contactor connected in one supply line to the welding transformer, under the control of the electronic timer. Weld time can be varied from 0·1 to 10 seconds, according to the setting of the automatic controls; the timer operates entirely off 50-cycle single-phase alternating-current mains.

In butt-flash welding one of the most remarkable achievements has been the rail-welding machine used by the London Passenger Transport Board for welding their running rails in units of 300 ft. Another remarkable feat was the butt-flash welding carried out in connection with "Operation Pluto."

"Sifbronze" Welding.—By employing "Sifbronze" welding the time for the operation is reduced by about 50 per cent., and the risks of burning the thin steel fittings obviated because the welding is completed at 800° C. (red heat). A neat finish is obtained by "Sifbronze" welding, and this also rules out the need for dressing the finished weld or straightening up the part, and owing to the low temperature involved, no normalising operation is necessary. Obviously this results in a considerable saving of gas and materials.

"Sifbronze" will weld together most materials (except Alpha brasses because these possess very low strength in welded condition, and alum and its alloys), whether they be alike or dissimilar. Thus copper and steel can be welded together satisfactorily; but if there is any doubt, test pieces should be made up and approved.

Before welding, *all parts must be cleaned* to remove any grease or dirt. It is usual to employ oxy-acetylene flame; but other flames can be used provided they are sufficient to melt the "Sifbronze."

"Sifbronze" flux is applied to the parts to be welded, either in powder form or mixed with water to form a paste. The end of the welding rod is then warmed and dipped into the flux. The welding flame should be slightly oxidising to melt a drop of "Sifbronze" around the components. When the parent metal reaches the correct temperature (i.e. red heat), this drop spreads out and tins the parent metal. Always weld leftwards, and if the weld is not of sufficient thickness in one run, a second or third run may be made, either on top of the other or side by side, without any treatment of the previous weld.

Often large complicated fittings require some pre-heating, but this need only be to quite a low temperature, and finally, after welding, the component will require cleaning but no heat treatment. The weld tensile strength varies from 28 to 40 tons per square inch weld, according to type of "Sifbronze" used.

This type of welding is well suited for all low-stressed welds, providing a useful length of weld fillet can be used. To make a fully satisfactory job it would be desirable to "fill up" the seams around the edges of the component part, as "Sifbronze" runs and "builds up" very easily. It would also appear to provide the answer to a quick and effective method of securing nuts to nut plates, etc.

LUBRICANTS

A suitable lubricant properly applied to contacting members which are moving relative to each other has the effect of interposing a liquid film or cushion between the parts, so that the friction of solid bodies rubbing against each other is replaced by fluid friction. The lubricant film conducts away some of the frictional heat from the contacting parts or bearing surfaces, and so tends to keep the parts cool.

When the contacting pressure between two moving surfaces is small, and when the motion of the parts is comparatively slow, only a small amount of lubricant is needed for the adequate lubrication of the parts. In instances such as these, a plastic solid such as a grease will suffice as a lubricant and will not require continual renewal.

When rapidly moving members bear upon each other with considerable pressure, a comparatively large amount of lubricant is necessary for the adequate lubrication of the parts. It is often necessary to circulate continually the lubricant between the contacting parts and through some type of cooling device in order to conduct the heat away from the working parts and to dissipate it harmlessly.

Action of the Lubricant.—When an oil film exists between two metal surfaces, a portion of the film is actually adsorbed into the surface layers of the metal. There is another "boundary" film existing just on the surface of the metal, whilst the "full fluid" film is that portion of the oil film which exists between the two metals.

The thinner the film of oil existing between two metals the less must be the actual thickness of the middle "full fluid" film. In extremely thin oil layers between contacting metals this "full fluid" film practically disappears altogether, the opposing metal surfaces being separated merely by the two "boundary" films.

The opposing boundary films of oil, adopting the motion of their adjacent metal surfaces, rub up against the middle "full-fluid" film existing within the oil layer.

Instead, therefore, of having a dry metal-to-metal contact, we have two oil-to-oil contacts. Some friction is generated even under these conditions, but fluid friction is much less than the friction of solid bodies, and in consequence frictional heat between the two metal surfaces is kept down to a minimum.

The "Cushioning" Effect.—When a fairly thick film of viscous oil can be maintained between two opposing surfaces, frictional resistance is at a minimum because the middle "full-fluid" film attains a maximum thickness together with a maximum "cushioning" effect.

When, however, the oil layer between two parts moving at high speeds is extremely thin, the "full-fluid" film becomes almost non-existent. In these circumstances, the friction set up is between boundary film and boundary film. The resistance between these two films is much increased on account of the absence of any intervening "full-fluid" oil film.

The essential property of a lubricant is its viscosity. Viscosity is *not* mere stickiness, as it is often considered to be. Scientifically, viscosity may be described as a measure of resistance to flow. It is, therefore, the internal friction of a liquid, the friction existing between its constituent particles. The viscosity of a liquid has no direct relation to its density, colour, heat capacity, volatility, or other physical properties. In all oils, the property of viscosity rapidly decreases with increase of temperature. Hence, an oil which can satisfactorily maintain its "body" or viscosity at an elevated temperature is usually of maximum lubricating efficiency. If, however, its viscosity fails when the oil becomes heated up, the oil tends to be forced away from the contacting parts and a "dry" or almost dry metal-to-metal friction inevitably ensues.

Varieties of Oil.—The actual thickness of the adsorbed and boundary films of oil on a metal surface are governed, not only by the chemical nature of the oil, but also by the actual nature of the metal itself. Some metals "oil up" better than others, though exactly why this should be the case is not yet known. Modern research, however, is actively investigating these problems.

Vegetable and animal oils suffer under the decided disadvantage of absorbing oxygen from the air and becoming rancid, thick, and sticky in consequence.

Mineral oils are more or less inert in such respects, and can usually be guaranteed to retain their essential properties indefinitely.

Blended Oils.—Many commercial oils and greases are blends of mineral and vegetable oils, castor oil being one of the most commonly used lubricants of the latter type. Blended lubricants stand up to high temperatures without losing their viscosity, and it is said that they permit the formation of a thicker middle "full-fluid" film in the layer of lubricant existing between two contacting parts than do the mineral oils alone.

Measurements of the thicknesses of oil layers existing between two opposing metal parts have frequently been taken, and it has been shown that, under practical conditions of high-speed machine working, the total layer of lubricant between two contacting members is often not more than about 0·001 in. in thickness. Sometimes the lubricant layer becomes even thinner, particularly under high-temperature conditions of working.

Causes of Oil-film Breakdown.—That lubricant films will at times break down under conditions of high velocity of their opposing metal parts is well known, and it is now considered that such oil-film breakdown begins locally in very small areas. In such areas it is thought that the inter-molecular forces between the opposing metals become so strong that the thin film of lubricant existing between the metal particles is unable to insulate them. In such areas, therefore, the lubricant film is punctured and the opposing metal particles attract one another. Tiny points or "hot spots" develop, and these minute areas generate excessive heat so that, the metal being raised in temperature above its melting-point in these minute areas, a species of local welding occurs. More excessive heat is thereby generated and, in consequence, the condition rapidly spreads until the whole bearing seizes.

The use of oils containing colloidal graphite has extended rapidly during recent years, since the graphite, being in an extremely fine state, is forced between the particles of metal existing in the surface layers of the contacting members. In such instances, the tendency to the formation of incipient "hot spots" is lessened, and hence the liability to breakdowns of ultra-thin oil films between high-speed moving and heavily contacting parts is lowered.

The first unit to receive attention is the nipple or lubricator. Much thought and ingenuity have been expended on the design of nipples for specific purposes.

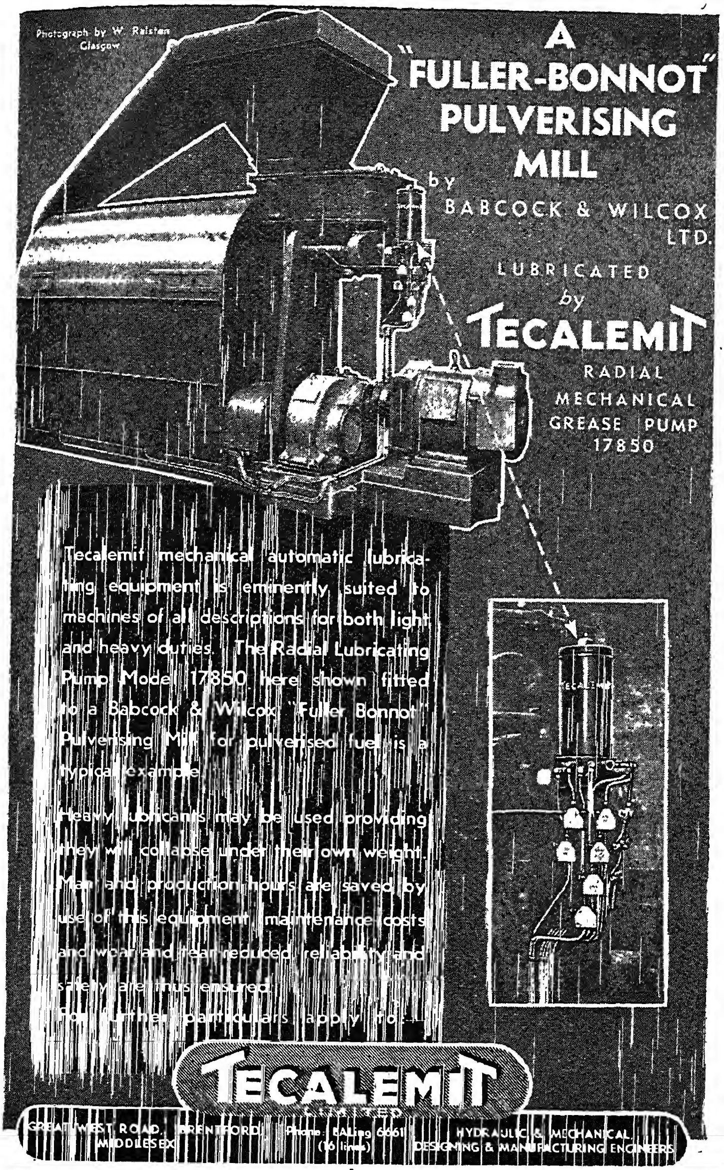
When an exceptionally high pressure is applied to clear a badly clogged bearing it is often found that the nipple will fracture, and sometimes, with air-operated high-pressure guns, the enormous pressure generated by the gun in such emergency makes it virtually impossible to hold the appliance in position. To obviate the time-wasting alternative of dismantling the bearing, the special steel adapter or "clearing nipple" is used. It is simply inserted in place of the standard nipple (which is unscrewed), the gun is hooked on by means of its special hook-type adapter, and pressure is applied direct to the bearing. The standard nipple is then replaced. Sets of these steel adapters are usually kept on hand with threads to suit all the plant in use.

This matter of the pressure forcing the appliance away from the nipple applies, of course, only to "contact nipples," and not to the hook-on or clip-on types.

High-pressure Guns and Injectors.—While for certain limited applications the simple hand gun will always remain the obvious tool, it has been superseded by the power instrument in all cases where any considerable amount of use is necessitated. The power gun falls broadly into three main groups, viz., portable gun, stationary unit with flexible hose, and pistol or permanently coupled mechanical equipment, according to the class and quantity of lubricant handled, the power usually adopted being compressed air.

The principle of operation is that of the hydraulic ram; in this case the pressure of air at 100–125 lb. per sq. in. on a large-area piston is converted into pressure on the lubricant by a small ram, and the ratio of areas and stroke is such that a final pressure of between 4500 and 5500 lb. per sq. in. is obtained at the nipple. This class of gun usually weighs about 4½ lb., and delivers a definite measured quantity of lubricant with each "shot." An alternative form will be found which is automatic in action, continuing to supply lubricant as long as the trigger is depressed.

Larger Stationary "Boosters."—Larger plants are built as a unit to operate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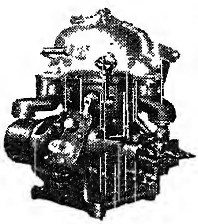

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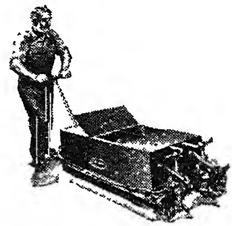
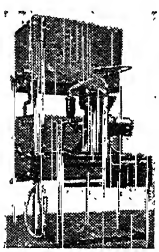


DE LAVAL OIL TRANSPORTER
enables cutting oil, lubricating oil, paraffin, etc., to be quickly carried from stores to machines and from machines to reclaiming plant. Tank capacity 80 gallons.



DE LAVAL HEATING TANK UNIT
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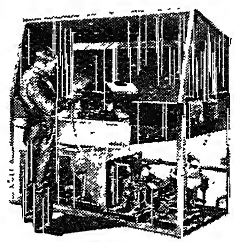

DE LAVAL "PARAWASH" EQUIPMENT
for washing machine parts. Self-contained Unit incorporating De Laval Oil Purifier, High-pressure Pump and Pistol-type Spray Gun.

Modern Machine Shop Practice

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'Phone : EALING 0116 (P.B.X.)

on the standard air supply at 125–150 lb. per sq. in.; its scope is much wider than the simpler portable gun, and its capacity is correspondingly greater. This type of "booster" is intended to accommodate a 1-cwt. keg of oil or grease without the messy business of handling and transferring it to smaller containers.

The booster unit is a combined air motor and force pump built in a column; air is delivered into the cylinder via a valve-box and a slide valve which trips over at each end of the stroke. The rising and falling piston operates a ram immersed in the lubricant; the pressure is built up, and fed to the one or more guns, or, alternatively, to the bearings direct.

Much will depend on the type of machinery being lubricated; for instance, in the case of several small units requiring only occasional attention the small portable gun is sufficient, or, if the work is scattered over a large floor area and large quantities of grease are involved, the larger booster will be a necessity. In the case of work involving many distant points and large quantities of lubricant, the ideal arrangement is to install the large booster unit in a portable trolley and equip it with air and grease hoses by means of which it may be coupled to air points in any part of the works, and be quickly moved from place to place.

An alternative arrangement is that of the stationary booster, or sometimes even a battery of them, installed at one convenient point, and having their own electric or air supply, connected by suitable pipework to either a suspended hose and pistol at each machine or a central swing arm with a working radius such as to reach several machines. Lastly, when there is objection to hoses or cables trailing the floors or suspended from above, a method sometimes used is to have two or more hose-reeling towers at convenient points, the hoses being withdrawn and automatically re-reeled after use.

Grouped Nipples and Remote Units.—The advantages of the modern practice of grouping the lubrication points are numerous, the possibility of any point being overlooked is removed, and, in the case of plant requiring frequent lubrication while in operation, dismantling and the removal of safety guards with the attendant disruption of output and risk of accident are entirely eliminated.

Examples of Group Nipple Layouts.—It will often occur that combined installations on one large plant will require two different lubricants, i.e. standard light grease and high-melting-point grease, or, as will be found in certain plate-joggling or metal-working plant, certain points require grease and others semi-solid or viscous oil. With standard independent nipples confusion can easily occur, but the grouping system overcomes this by leading the lines to two panels, one for each class of lubricant. Thus, by having different types or sizes of nipple and injector it becomes impossible to err, as only the correct appliance can ever be used on either panel.

Automatic Gear for Grease as Distinct from Oil.—Although grease is specifically mentioned in this connection, it will readily be understood that the description covers roughly any grease which is sufficiently soft to collapse under its own weight and any heavy oil such as very thick gear oil, semi-grease, and similar viscous lubricants. The lighter types of lubricant, of course, require different treatment and are discussed later.

Mention was made earlier of the practice of piping the various points to a single panel, the group nipple arrangement; from this the evolution of automatic supply in its simplest form is easily seen. The attachment of an air-driven "booster" and a set of control valves eliminates the manual manipulation of guns or injectors, and further development includes the provision of a separate panel and gauges apart from the machinery and coupled by pipelines. Such provides a multi-point grease battery for lubrication of two high hot roughing and finishing bar mills.

It will be noted that in this type of installation no drive is picked up from the machinery, and the position of the panels and boosters may be varied to suit the layout. If space be restricted, the panel may be many feet away from the plant.

In cases where it is convenient to pick up a drive from an existing sprocket or pulley, or when there exists an adjacent spindle or gear on a machine, self-contained automatic grease pumps or distributors provide a ready and convenient method of doing the work of lubrication by making the machine itself responsible for feeding several points under pressure.

High Pressure and Measured Quantities.—One of the finest and most interesting examples of mechanical greasing plant is the electrically driven Tecalemit "Line-o-Matic" grease compressor. This self-contained apparatus, consisting of motor, container, pressure pump, and control mechanism, provides certain and foolproof lubrication of almost unlimited numbers of lubrication points.

The compressor is arranged to feed through a single line to adjustable "injectors" delivering a fixed and measured quantity at each operation of the compressor; the unit is fixed at a central, safe, and convenient point and piped to the "injectors."

The same system (single line and individual branches) is also used with air-driven or even manual grease compressors in place of the electric unit. Oil is, of course, light, medium, or heavy lubricating oil, *not* the more viscous or tenacious styles, such as gear oil or similar thick fluids. Whilst, in the main, the distribution and pipework connected with oil are similar to those for the heavier lubricants, the pressures encountered (except in certain cases) are of a much lower order. The system generally may be of lighter construction; in place of the hydraulic lines and fittings used for grease, etc., standard pipes and fittings only are required.

Automatic feeds of external oiling systems may have a variety of units as the pumping force. A typical example is the Tecalemit oil pump, which consists of a body containing the pumping mechanism and a set number of outlet points, the outlets being taken via sight-feed glasses, fitted on the pump body for each individual line. Control knobs for adjusting the rate of flow are also provided; these knobs are serrated and spring-loaded to ensure that they "stay put" against the effects of vibration.

Lubrication of Steam Engines.—For steam engines there are three methods of lubrication in general use, viz.:

(1) The ordinary gravity system of lubrication, in which the oil is simply allowed to run or drop upon the bearing or surface to be lubricated, being fed by some suitable lubricator or pipe led from a cistern or reservoir.

(2) The splash system of lubrication. When this system of lubrication is adopted all the motion work of the engines is enclosed in a case forming the engine frame and base. This system is only used for engines of the high-speed type. The base of the engine is filled with oil and water to such a level that the cranks dip as they revolve and so throw the lubricant on all parts requiring lubrication.

(3) Forced-lubrication engines. In this system all bearings and slides are supplied with oil under pressure; that is, all parts are coupled up by pipes to a common pump, which forces the oil between the surfaces to be lubricated.

Bearings are frequently lubricated with grease instead of oil; but in this case each bearing is usually supplied with its own pump or lubricator, which forces in the grease under pressure.

Systems (1) and (3) are used in connection with all classes of machinery and gearing, but (2) is only used for high-speed engines of the single-acting type similar to those made by Messrs. Willans & Robinson.

Friction.—Friction is of three kinds—dry friction, viscous friction (that is to say, where the surfaces are separated by the oil film), and greasy friction, where the surfaces, although still in contact, are lubricating. In the case of viscous friction sufficient clearance must be provided to permit of an unbroken film of oil, and this must be circulated under high pressure. Oil-pressure systems in motor-cars vary from 15 lb. per sq. in. to 60 lb. per sq. in. In high-efficiency engines it is necessary to cool the oil, and in aircraft engines viscosity valves are introduced for that purpose.

The flow of oil conducts the heat away from the bearings. It is important to filter the oil.

For slow-moving bearings greases are often used, although there is considerable risk of the grease solidifying. Thick oil under such conditions is preferable. Most of the commercial brands of oil, if of good grade, maintain reasonably consistent viscosity. Some oils lose bulk after continued exposure to high temperatures, and such oils are therefore unsuitable.

Bore.—Internal diameter of cylinder.

Stroke.—Distance of sweep of piston from top position to bottom position.

Plug Points.—As a rule the setting of plug points for the ordinary engine is one-fiftieth of an inch. Can be as much as one-sixteenth of an inch.

Tappet Clearances.—The general practice is to allow three-thousandths of an inch clearance for the inlet valves and four-thousandths of an inch for exhaust valves, measured when the engine is cold.

$$\textbf{Compression Ratio} = \frac{\text{Volume of space above piston at bottom of stroke}}{\text{Volume of space above piston at top of stroke}}.$$

90 lb. per sq. in. is the pressure often reached in the combustion chamber before mixture is ignited. Usual compression ratio is from 5 to 1 to 7 to 1, according to fuel used. The highest useful compression is that which does not cause detonation.

Mixture Ratio.—This varies according to the fuel used.

Mixture Ratio (by weight) of Air to Fuel

Paraffin	15·2 to 15
Naphthenes	14·7
Aromatics	13·6 to 13·2
Alcohols	8·95 to 6·44

Piston Clearances.—Cast-iron pistons two-thousandths of an inch at skirt and three-thousandths of an inch at crown. With light-alloy pistons, clearances depend on nature of material used.

Indicated Horse-power.—This may be calculated from an indicator diagram:

P = Mean effective pressure in pounds per square inch.
L = Length of stroke in feet.
A = Area of piston in square inches.
n = Revolutions per minute.
N = Number of cylinders.

$$\text{Indicated H.P.} = \frac{PLANn}{33{,}000}.$$

Formulæ for H.P.—

S = Stroke in centimetres.
D = Diameter of cylinder in centimetres.
R = Revolutions per minute.
N = Number of cylinders.

$$\text{R.A.C. formula: H.P.} = \frac{D^2 \times N}{16{\cdot}13}.$$

A.C.U. (and proposed new Treasury rating) formula: 100 c.c. = 1 h.p.
A more accurate formula is the Dendy Marshall, in which:

$$\text{H.P.} = \frac{D^3 \times S \times N \times R}{200{,}000}.$$

Brake Horse-power.—This is measured by a brake or dynamometer.

$$\text{Brake H.P.} = \frac{\text{B.H.P.}}{\text{I.H.P.}} \times 100.$$

Firing Order.—If the timing of any motor is not known, it can be ascertained by following the action of the inlet valves, starting with No. 1 cylinder, then noting next inlet valve to open, as the engine is slowly cranked in normal direction of rotation.

When turned in proper direction, the inlet valve will open immediately after the exhaust valve closes.

Cylinder Bores and Strokes in Millimetres and Inches

(An Approximate Guide for Comparison)

A cylinder measuring: *mm.*	*in.*	A cylinder measuring: *mm.*	*in.*
80 × 80	= $3\frac{1}{8} \times 3\frac{1}{8}$	108 × 120	= $4\frac{1}{2} \times 4\frac{3}{4}$
80 × 86	= $3\frac{1}{8} \times 3\frac{3}{8}$	110 × 125	= $4\frac{5}{16} \times 4\frac{15}{16}$
83 × 83	= $3\frac{1}{4} \times 3\frac{1}{4}$	112 × 128	= $4\frac{7}{16} \times 5\frac{1}{16}$
83 × 86	= $3\frac{1}{4} \times 3\frac{3}{8}$	114 × 130	= $4\frac{1}{2} \times 5\frac{1}{8}$
86 × 86	= $3\frac{3}{8} \times 3\frac{3}{8}$	116 × 134	= $4\frac{9}{16} \times 5\frac{7}{16}$
84 × 90	= $3\frac{5}{16} \times 3\frac{9}{16}$	118 × 138	= $4\frac{5}{8} \times 5\frac{7}{16}$
90 × 90	= $3\frac{9}{16} \times 3\frac{9}{16}$	120 × 140	= $4\frac{3}{4} \times 5\frac{1}{2}$
90 × 100	= $3\frac{9}{16} \times 3\frac{15}{16}$	122 × 143	= $4\frac{3}{16} \times 5\frac{5}{8}$
95 × 115	= $3\frac{3}{4} \times 4\frac{9}{16}$	124 × 146	= $4\frac{7}{8} \times 5\frac{3}{4}$
100 × 115	= $3\frac{15}{16} \times 4\frac{9}{16}$	126 × 148	= $4\frac{15}{16} \times 5\frac{3}{16}$
105 × 118	= $4\frac{1}{8} \times 4\frac{5}{8}$	128 × 150	= $5\frac{1}{16} \times 5\frac{15}{16}$

Calorific Value of Fuel.—This is the amount of heat developed during combustion, ascertained by burning in a calorimeter.

For properties of gases, see separate section.

Thermal Efficiency.—This is the ratio of heat made use of to the total heat supplied.

$$\text{Thermal efficiency} = \frac{(\text{Heat supplied} - \text{heat rejected})}{\text{Heat supplied}}.$$

Tyre Size Equivalents

(Approximate)

mm.		*in.*	*mm.*		*in.*
65	=	$2\frac{1}{2}$	650	=	26
80	=	3	700	=	28
85	=	$3\frac{1}{4}$	750	=	30
90	=	$3\frac{1}{2}$	800	=	32
100	=	4	870	=	34
105	=	$4\frac{1}{4}$	910	=	36
120	=	5	1010	=	40

Speed per Yard.—Table showing varying distances covered in one second and the corresponding speed in miles per hour:

yards		*m.p.h.*	*yards*		*m.p.h.*
$4\frac{8}{9}$	=	10	$29\frac{1}{3}$	=	60
$9\frac{7}{9}$	=	20	$34\frac{2}{9}$	=	70
$14\frac{2}{3}$	=	30	$39\frac{1}{9}$	=	80
$19\frac{5}{9}$	=	40	44	=	90
$24\frac{4}{9}$	=	50	$48\frac{8}{9}$	=	100

Speed in M.P.H.—To find speed in miles per hour when time for measured distance is known:

$$\text{M.p.h.} = \frac{45 \times \text{distance in yards}}{22 \times \text{time for distance in secs.}}$$

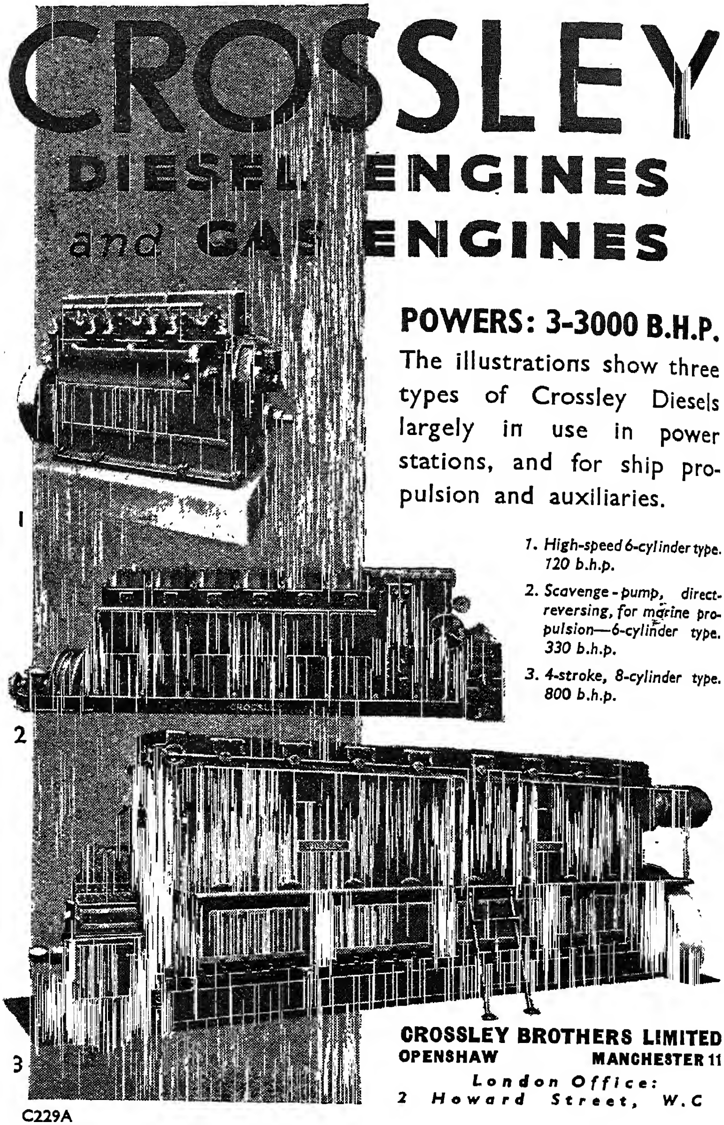
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TABLE SHOWING RELATION BETWEEN ENGINE REVOLUTIONS PER MINUTE AND SPEED IN MILES

Gear Ratio	Speed in Miles per Hour																		
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
3	390	585	775	970	1165	1360	1555	1750	1945	2135	2330	2525	2720	2915	3110	3305	3500	3690	3885
3·2	415	620	825	1035	1240	1450	1655	1860	2065	2275	2485	2690	2895	3100	3310	3520	3725	3930	4140
3·4	440	660	880	1100	1320	1540	1760	1980	2200	2420	2640	2860	3075	3300	3520	3740	3960	4175	4400
3·6	465	700	930	1165	1395	1630	1860	2090	2330	2560	2790	3025	3260	3490	3720	3960	4100	4420	4660
3·8	490	735	980	1225	1470	1715	1952	2210	2455	2700	2945	3185	3435	3680	3925	4170	4420	4660	4915
4	520	775	1035	1295	1555	1810	2070	2330	2590	2850	3115	3365	3625	3880	4145	4405	4665	4920	5180
4·2	545	815	1085	1355	1630	1920	2170	2445	2720	2985	3260	3530	3800	4075	4345	4620	4885	5160	5430
4·4	570	855	1140	1420	1705	1990	2275	2560	2845	3130	3420	3700	3980	4270	4560	4840	5125	5410	5695
4·6	595	890	1190	1485	1780	2080	2375	2675	2975	3270	3565	3865	4160	4460	4760	5055	5350	5650	5945
4·8	620	930	1240	1550	1860	2170	2480	2785	3110	3415	3725	4035	4350	4660	4970	5280	5580	5900	6205
5	645	970	1295	1615	1940	2260	2585	2915	3235	3560	3880	4210	4535	4855	5180	5500	5825	6145	
5·2	670	1010	1345	1680	2015	2355	2680	3025	3365	3700	4035	4375	4710	5045	5380	5715	6060		
5·4	700	1045	1395	1745	2090	2440	2790	3145	3495	3845	4195	4545	4895	5245	5480	5945	6295		
5·6	725	1085	1445	1810	2170	2535	2900	3260	3620	3980	4340	4710	5080	5430	5795	6160			
5·8	750	1125	1500	1875	2250	2625	3005	3375	3755	4130	4510	4880	5255	5630	6010				
6	775	1165	1550	1940	2325	2715	3110	3490	3880	4270	4660	5045	5430	5825	6205				

This table relates to 26-in. tyres. For 24-in. tyres multiply revolutions by 1·08. For 28-in. tyres multiply revolutions by 0·93.

Engine Capacity.—Engine capacity = square of diameter × 0·7854 × stroke × number of cylinders.

Sparking-plug Screw Threads.—Plugs are made in seven sizes—18 mm., 14 mm., 12 mm., 10 mm., ⅞ in., ⅝ in., and ½ in. Details of pitches and thread standards are given on p. 616.

Fuel Consumption.—From many tests it has been shown that the "air standard" thermal efficiency of an engine is $E = 1 - \left(\frac{1}{r}\right)^{0\cdot4}$. From all considerations this is known to give too high a value, and a modified formula is $E = 1 - \left(\frac{1}{r}\right)^{0\cdot296}$, which gives results of the order of 80 per cent. of the "air standard" figures.

Tractive Effort.—The tractive effort at the road surface is found from the formula:

$$T_e = \frac{T_i \times r \times e}{D/2}$$

where T_e = Tractive effort at road surface.
T_i = Torque of engine in lb.-in.
r = Gear ratio in use.
e = Mechanical efficiency.
D = Wheel diameter in inches.

Average Piston Speed.—The average piston speed is found from:

$$k = ns/360 \text{ ft. per sec.}$$

where k = Average piston speed.
n = R.p.m.

Valves.—These are generally made of a heat-resisting steel, such as silicon chrome. Valves should be so designed that gas velocity through them does not exceed 135 ft. per second.

Let X = Mean gas velocity in feet per second.
A = Area of piston in square inches.
s = Stroke in inches.
a = Valve area.
n = r.p.m.
h = Piston speed in feet per second.

Then: X = Ah/a feet per second.
a = Ah/X square inches.

Connecting Rods.—Connecting rods are subject to three stresses: (x) a direct end thrust due to gas pressure on the piston:

$$x = \frac{\pi}{4}d^2p/A,$$

here d = Piston diameter in inches;
p = Gas pressure calculated throughout the stroke as already described;
A = The cross-section area of the rod in square inches;
w = Weight of reciprocating parts.

(y) the end thrust due to acceleration of the reciprocating parts:

$$y = \frac{wa}{32\cdot2}/A;$$

and (z) the transverse bending moment due to acceleration during the lateral swing of the rod:

$$z = \frac{An^2rl^2}{2Z \times 10^6}$$

here n = r.p.m.;
l = Length of rod in inches;
Z = Modulus of section;
r = Radius of crank in inches;

then the algebraic sum of $x + y + z$ is the total stress per square inch cross section of rod.

Brooklands Track

One circuit on centre line	2 miles 1350 yards.
One circuit at 10 ft. from inner edge	2 miles 1263 yards.
Width of track	100 ft.
Length of finishing straight	991 yards.
Maximum height of banking on shorter curves	28 ft. 8 in.
Radius at which curve of track is struck :	
Byfleet banking	1500 ft.
Members' banking	1000 ft.
Mileage expressed in laps (on centre line) :	
100 miles	36·14 laps.
1000 miles	361·42 laps.
Surface length of Test Hill	352 ft. 3 in.
Average gradient of Test Hill	1 in 5·027.
Maximum gradient of Test Hill	1 in 4.

Brooklands Distance Table

The length of the complete lap on the 50-ft. line is 2·76688 miles.
= 4869·70483 yards
= 4·45 kilometres.

Laps	*Miles*	*Laps*	*Miles*	*Laps*	*Miles*	*Laps*	*Miles*
1	2·76688	20	55·33755	39	107·90823	58	160·47891
2	5·53376	21	58·10443	40	110·67511	59	163·24579
3	8·30063	22	60·87131	41	113·44199	60	166·01266
4	11·06751	23	63·63819	42	116·20887	61	168·77954
5	13·83439	24	66·40507	43	118·97574	62	171·54642
6	16·60127	25	69·17194	44	121·74261	63	174·31330
7	19·36814	26	71·93882	45	124·50950	64	177·08018
8	22·13502	27	74·70570	46	127·27636	65	179·84706
9	24·90192	28	77·47258	47	130·04325	66	182·61394
10	27·66878	29	80·23945	48	132·81013	67	185·38081
11	30·43566	30	83·00633	49	135·57701	68	188·14768
12	33·20253	31	85·77321	50	138·34389	69	190·91456
13	35·96941	32	88·54009	51	141·11076	70	193·68144
14	38·73629	33	91·30697	52	143·87764	71	196·44832
15	41·50317	34	94·07384	53	146·64452	72	199·21520
16	44·27004	35	96·84072	54	149·41140	73	201·98208
17	47·03692	36	99·60760	55	152·17828		
18	49·80384	37	102·37448	56	154·94515		
19	52·57068	38	105·14135	57	157·71203		

Equivalent Miles and Kilometres per Hour

M.p.h. × 1·609 = K.p.h.
K.p.h. × 0·6214 = M.p.h.

M.p.h.	*K.p.h.*	*M.p.h.*	*K.p.h.*	*M.p.h.*	*K.p.h.*
1	1·609	30	48·270	60	96·540
5	8·045	35	56·315	65	104·585
10	16·090	40	64·360	70	112·630
15	24·135	45	72·405	75	120·675
20	32·180	50	80·450	80	148·720
25	40·225	55	88·495		

The use of metal such as iron, steel, and aluminium for the panels of motor bodies has developed this branch of the sheet-metal worker's craft, and been responsible for the production of special tools and methods for bringing the metal to the required complex form. Methods vary according to the purpose, size, and workshop. Some panels are part-pressed before being hand beaten to shape to conform with the body lines. The latest development is stretch-forming, in which process the sheet of metal is stretched and at the same time pulled over a mould of the required shape. Even here, final handwork is necessary to ensure continuity of curve and alignment with the body frame.

Most panels are blocked out on sandbags, by means of pear-shaped or round-headed mallets, and their shape is determined by the frames or jigs to which the panel is frequently referred during the panel-beating process. When the panel accurately fits the jig it is planished, tapped to the jig, marked off for size, and the surplus material cut away.

In commencing work on a body, the first operation is the preparation of a paper pattern of the actual shape of the panel to serve as a guide in cutting up the sheet of metal. The more accurate the pattern the greater the economy of material and ease of handling.

The paper is pinned into position on the top first and carried down the framework, where it is secured in position. Next carry it down the back standard, and where the centre of the corner radius lies fold up the paper as close as possible at the bottom, and work up a wedge-shaped fold, terminating at a point about half-way up. The fullness necessary is obtained by pressing out the paper where required. In the case of a quarter-panel the corner, side, and back views will be as in Figs. 7 and 8. When the paper pattern is removed and cut out it will be generally as in Fig. 9. The taper lines indicate the extent of corner radius, and the actual piece, which will be cut out of the pattern and later from the panel, will be in the form of a convex-sided V. The sides of the metal are held together and welded up. The cutting out of this V eliminates the large amount of gathering which would otherwise be necessary to produce the bulbous-shaped corner. Fig. 9 shows the pattern.

In gathering, the panel must be held firmly by the left hand against the body of the operator, and with the edge of the panel about 3 in. above the edge of head, as shown at A in Fig. 2. The edge should be given two sharp blows, one on both sides of the actual point of contact of the panel on the head. This forms a pucker on the edge of the panel. By working towards the edge of the panel on an ordinary head from the point to which the pucker extends, the metal will thicken up at the edge and so cause a bulbous shape to result. By repeating this process every few inches along the edge, the above-mentioned action is increased proportionately.

When the edges are welded up the join will be definitely angular, and the next operation is to disperse the angle on lines indicated by the fan lines. The bottom edge is gathered as indicated by the wedge-shaped lines.

Dispersing.—The head for dispersing the angle above mentioned is a special one, and should be flatter than the ordinary heads so that blows given on it dent the panel repeatedly, which in a manner "upsets" the metal and so reduces it, enabling the whole to be evened out satisfactorily. An illustration of this head is given in side or end elevation by Fig. 10, and on the latter the relative compasses of head and panel are shown. As with most heads, it is oval in shape, but the corners are of sharper radius. The size is about 5 in. by 4 in. Having reduced the angle and gathered the lower edge, the panel is tried up to see if the general shape is correct, and then if further gathering is required, which is likely, it should be done.

Correcting.—If the compass is too quick, the panel is laid face downwards on a block of hardwood and struck with a full-faced hammer, starting from the point where the superfluous fullness is apparent and working towards the edge with blows gradually increasing in weight. This treatment will disperse the too


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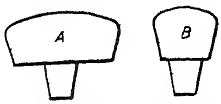


Fig. 1.—Heads for general work.

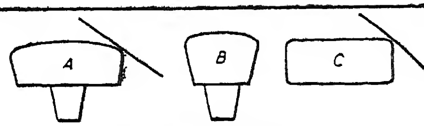


Fig. 2.—Gathering heads.

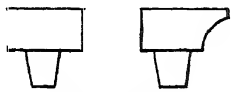


Fig. 3.—Anvils.

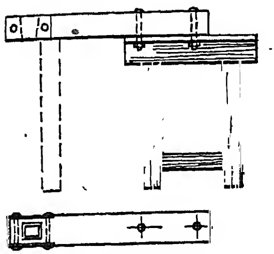


Fig. 4.—Support for heads.

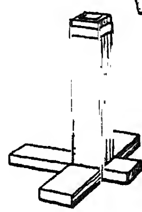


Fig. 5.—Another type of support.

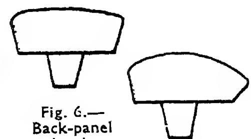


Fig. 6.—Back-panel heads.

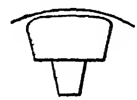


Fig. 10.—Dispersing head.

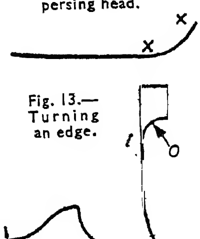
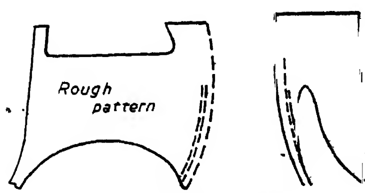


Fig. 13.—Turning an edge.



Figs. 7 and 8.—Pattern of panel.

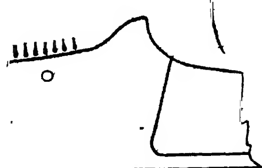


Fig. 11.—Stretching a scuttle dash.

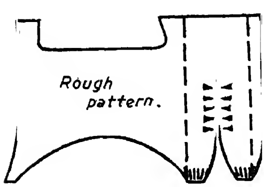


Fig. 9.—Pattern developed in flat.

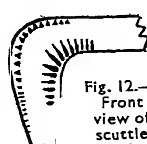


Fig. 12.—Front view of scuttle dash.

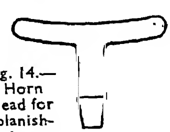


Fig. 14.—Horn head for planishing.

greatly contracted metal. Naturally, in this operation the course taken should be the shortest way to the edge of the panel.

Planishing.—Having got the general shape correct or nearly so, the panel is smoothed with a mallet on the proper head, working all over where the metal has been roughened. Try up again, and if correct planish with the planishing hammer on the correct head. The panel is now hammered with the planishing hammer all over to give the necessary general side sweep and turn-under beyond the range of the corner proper. In this operation the heads and planishing hammer should be perfectly smooth and clean; a faulty head or hammer will spoil the panel.

The more regular panels—doors and seat sides—are hammered face downwards only on the anvil or face upwards on a head, and care must be taken not to overdo the hammering.

Stretching.—The alternative to gathering is stretching by means of blows with a bossing mallet on a sandbag. The bossing mallet is conical, such as is used by plumbers. Stretching, however, upsets and distorts the fibres, generally thinning the panel at the apex of a bulbous corner, and causing the whole panel to require close and careful attention, where otherwise it would simply require running over with the planishing hammer to give it the right shape to fit side and turn-under sweeps.

For a scuttle dash with a return or ogee sweep, the rear edge is gathered and the front edge on corner is stretched.

To stretch at O (Fig. 11) start midway along the proposed concave portion with light blows, gradually increasing in weight towards the edge, as indicated. This curls up the edge, which is smoothed up by mallet and planished in the ordinary way. A front view of this dash is given in Fig. 12 to illustrate the course of the resulting action on the steel. The centres, both at dash proper and back edge, are generally nearly flat and can be worked up with the planishing hammer.

In turning an edge such as is illustrated in Fig. 13, gather from X to X; the puckers must extend no more than half-way over radius to O. In smoothing out, the metal will extend to I, and then the work may be planished on a small head or on a horn (Fig. 14) of a section and radius from end to end to suit possible work. The above rule applies in half-way puckering to corners and edges irrespective of the radius.

The split-and-weld system is much less laborious and quicker than the old system of panel beating. Any humps formed are dispersed by hammering on a suitable head.

Tools.—The tools required are first a selection of cast-iron heads on which the work is done. These vary in size and compass of face according to the size of curved panel to be produced. The general rule is that they shall be sharper in compass or radius than the panel will be when finished.

For general large work, such as back-corner panels of full-size bodies, a head about 8 in. long and 4 in. or 5 in. wide, and true oval in shape, will be required.

Other heads required are generally on the same lines, but in smaller sizes according to the work in hand. The actual depth of compass of face should be half an inch each way, and the actual edges of the face finish with a radius of about an inch. The depth of the head from crown to base is about 3 in.

A general small head 4 in. or 5 in. long and 3 in. wide of the same shape—oval with rounded edges—may almost be classed as a standard requirement. It must be remembered, however, that the work does not fit the head, but a head with a large area helps to steady the work and increases the facilities of striking in various places without the restrictions of a smaller head.

For "gathering," which is the process of contracting the metal at the edges of panels so as to give fullness to another part, a fairly small head is used with edges that are more square and with less compass on the face.

These heads given are, of course, only typical. They are not made and stocked as a standard article, but are cast from the user's own pattern at a local foundry. Cast iron is the material used, as steel has a tendency to break the hammers. The castings should be nice and clean, true and smooth as possible, and absolutely free from blow-holes on the face. They are finished by being either filed or ground smooth. Preferably they should be cast with the shank upwards, in order to prevent blow-holes and large irregularities on the face.

An item which may be purchased from stock is a panel-beater's anvil, which is a square flat-faced head (Fig. 3). Its chief use is for putting fullness on fairly level panels, such as door panels, seat-side panels, and any others which are rounded up by the planishing hammer only. In these cases the panel is held face down on this head and hammered on the inside. A joint return sweep may be worked up also by having the concave side upwards.

All heads should have a stump for insertion in a block, stand, or beam as required. The stumps should be of uniform size and shape, so that they may be changed about as desired.

The types of blow that can be struck on sheet metal are three: (1) a *solid blow*, where the work is struck solidly over a solid-metal head or anvil; (2) an *elastic blow*, where either the head or the tool (or both) is made of a resilient material, such as wood; and (3) a *floating blow*, where the head or anvil is not directly under the hammer.

Each type of blow has its uses for particular purposes. A solid blow will stretch the sheet, and may be necessary when forming a panel, bending a curved strip or angle, removing a loose or tight place in a sheet, or throwing an edge over when thickness is not a consideration. An elastic blow will form metal without undue stretching; indeed, if desired, metal can be thickened, as in working out a tuck or pucker. The floating blow is given to the metal when it is held over a suitable head and hit " off the solid," so forming " dents " at the points of impact.

Light alloy sheet material up to 18 S.W.G., and in some cases even 16 S.W.G., can be satisfactorily hand beaten by wood mallets into double-curvature forms.

Planishing.—Planishing is the finishing process by which the work-piece is smoothed off and set into its correct shape. It may be done with a flat steel hammer, with the wheel, or with a combination of both. It is best carried out with a large number of light blows, and for this reason a power-operated hammer giving blows at a rapid rate is often used. Where hammers are employed, the process is carried out over a convex head of iron. The planishing is carried out over the whole surface of the work-piece, the blows being light and given squarely; otherwise they will produce crescent marks difficult to eliminate. Each hammer blow produces a flat spot, and the blows are so directed that the spots merge imperceptibly into one another over the whole surface. Any low places or " valleys " on the surface of the work-piece can be eliminated by careful hammering on the head, which slightly stretches the metal, causing it to rise on the correct contours.

Both the hammer face and the convex head must be kept scrupulously clean and perfectly smooth, otherwise it will be impossible to avoid marking the sheet. Planishing should leave the metal with a dead smooth surface. If this is not attained, small hammer marks can be removed by smoothing off with emery cloth glued to a piece of wood and used like a file.

Wheeling.—Some craftsmen planish only with the wheel, though to obtain a good finish it is best used after planishing with the hammer. The wheeling machine itself consists simply of two wheels, one practically flat and the other convex, meeting at a common centre. The lower, convex, wheel is a free wheel of 2 in. or 3 in. in diameter on a spindle carried by a vertical arm which can be raised or lowered by a screw movement to regulate the pressure. The upper, flat, wheel, of 6 in. to 8 in. in diameter, is carried on a horizontal shaft.

Care should be taken, when using the wheel for the aluminium alloys, not to put too much pressure on the work. Up to three times as much " lift " is obtainable with the aluminium alloys as with steel, and much more shaping by wheeling is possible in the case of aluminium than with harder metals. It may be used simply to produce a smooth surface by the friction and rolling action derived from passing the sheet backwards and forwards between wheels of a shaped periphery.

Where parts of moderate curvature are to be produced by wheeling alone, the sheet to be shaped is placed between the two wheels at one edge or in the middle, and pressure of an intensity appropriate to the temper and gauge of the alloy is applied. The sheet is moved backwards and forwards through the wheels, each line of wheeling partially covering the next one, and by the repetition of the movement both longitudinally and transversely the metal stretches and so takes on a convex curvature. Movement of the sheet is varied until the desired shape is obtained, those parts of the metal which are required to be of slight curvature receiving less wheeling than the other more curved portions.

PIPE UNIONS, JOINTS, AND GLANDS

In connection with the controlled supply of air, water, oil, and petrol there arises the necessity for fitting various types of air- or liquid-tight joints. Petrol leaks are dangerous as well as expensive. All petrol pipes should be made of either soft, annealed copper tube, so that vibration will not cause cracks and breakages, or of special flexible tubing. Copper tubing can be softened, if brittleness is suspected, by heating to a dull red heat with a blow-lamp and immediately quenching in cold water.

Two kinds of union coupling (by means of which pipes are joined to the units they have to supply or from which the supply has to be drawn) are shown in Figs. 1 and 2. The first is the usual screwed union with external and internal cones, A and B, which are held together by a gland nut, C. They are sweated at D and E to the copper pipes which they are to join. It is important that the joint surface at X should be clean, and the internal cone ground into the external cone as a valve is ground on its seat. This can easily be done (the metal being comparatively soft) by means of pumice powder. The sweated joint at D or E may be separated by using a blow-lamp. This must be sweated up again after the joint has been ground. It is important to see that the gland nut C has free movement along the thread of B, so that cone A is pressed very tightly into B when the nut is tightened.

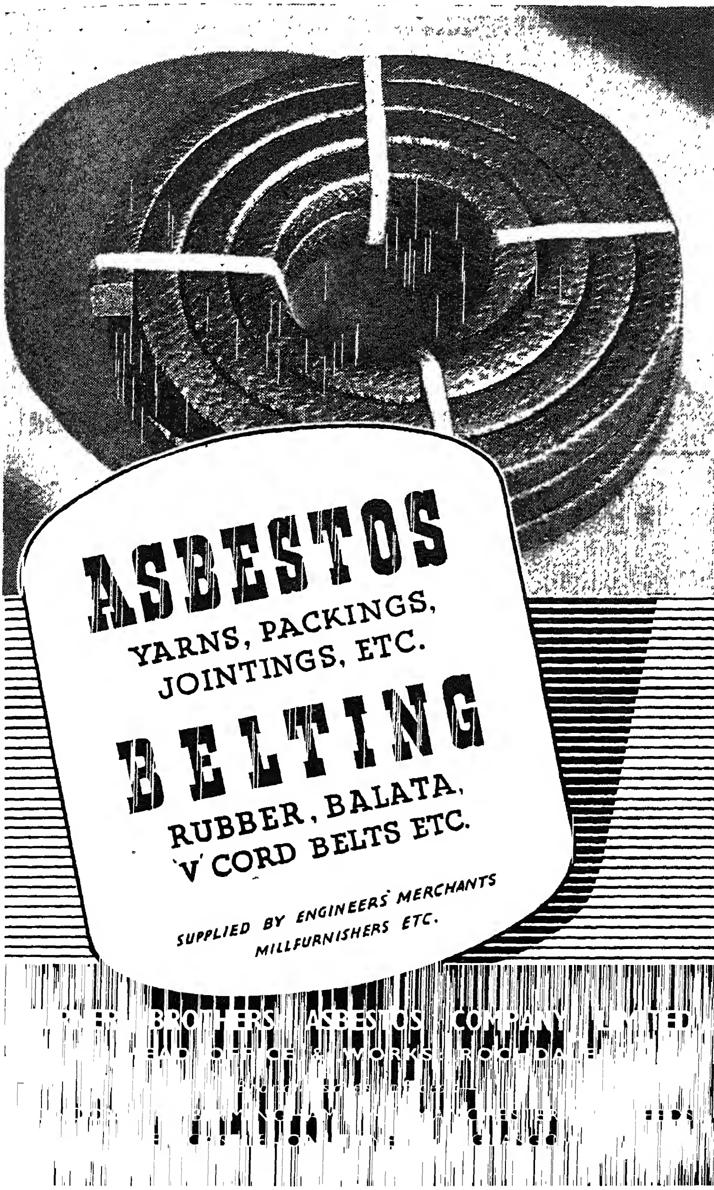
A union which does not require soldering is shown in Fig. 2. A small, double-ended cone, C, made of soft copper or brass with a very thin edge, enlarged and shown in section X, is slipped along the pipe. The two internal cones of gland and spigot, A and B, are at such an angle that the thin edge of the copper cone is pressed by the internal cones tight against the outside of the pipe, which is just slipped in and the union nut tightened up. In such a type of union care should be taken to see that the surface of the pipe, where the cone C lies along it, is quite smooth and clean.

Flanges.—For large pipes flat-flange joints are used, and these usually have thin packings. For water pipes, ordinary asbestos sheet makes a good packing if it is first soaked in liquid tallow; for exhaust pipes copper and asbestos washers must be used.

Flanged joints depend for efficiency on having their contacting surfaces perfectly flat. A section of such a joint is shown in Fig. 3. The packing washer is at A, and it is important that its central hole should register exactly with the bore of the pipe. If it is out of position it may cause considerable obstruction to the flow of gas or air due to vortices, which may result in loss of power. Such a condition is shown at X in Fig. 3, which is an end view of the joint with one flange removed. The dotted lines show the displaced position of the washer A. The holes for the studs B and C in the washer A should be of such a diameter that they fit the studs exactly. The central hole should be $\frac{1}{32}$ in. larger in diameter in the washer than in the pipe flange, because the former will push inwards into the bore when tightened up. This is most important in the case of inlet pipes from the carburetter to the engine.

Inlet and Exhaust Manifolds.—Some manifolds which carry the exhaust from the cylinder ports of internal-combustion engines are tightened up to the face on the cylinder to make a tight joint by means of cross-bars, one end of the cross-bar holding up a joint of the exhaust manifold and the other a joint of the inlet manifold. The arrangement is shown in front view and also in part section in Fig. 4. In this arrangement it is important that all the washers of the inlet manifold should be the same thickness, and also all the washers of the exhaust. The cross-bar or yoke, A, is held up to the two manifolds by a stud B and a nut C.

It is possible, if the stud is too tight a fit in the hole in the cross-bar, that the nut C will not be able to exert sufficient pressure on the inlet- and exhaust-manifold joints, D and E. There should be appreciable slack between the hole and the stud, as is shown in Fig. 4. This principle applies wherever two parts held by a cross-bar or yoke lie flat against the manifold, a point contact being almost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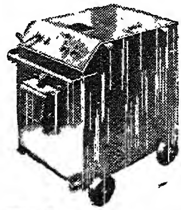

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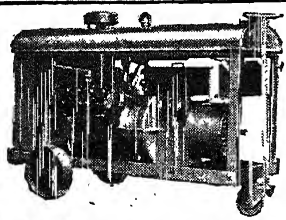

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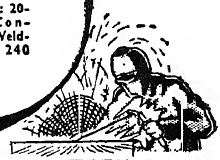

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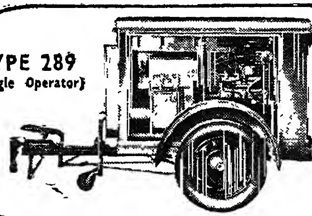

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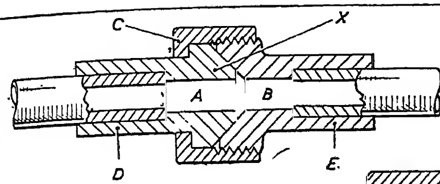


Fig. 1.—The usual type of screwed union with internal and external cones.

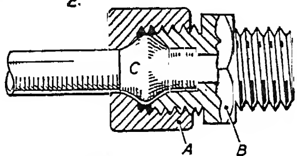
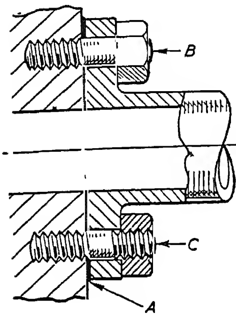
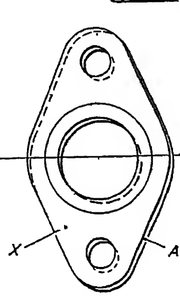


Fig. 2 (*Right*).—Using this type of union there is no need to employ solder.





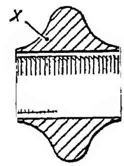


Fig. 3 (*Left*).—It is important that the central hole in the packing washer in this type of joint should register perfectly with the bore of the pipe.

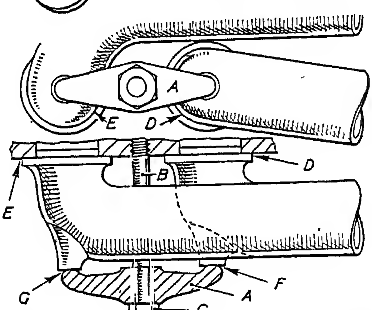


Fig. 4.—Showing how some types of inlet and exhaust manifolds are tightened up to the face on the cylinder by means of a cross-bar.

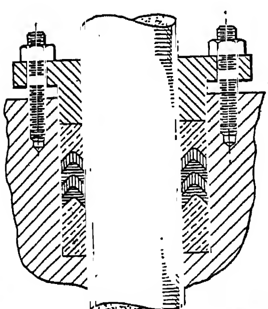


Fig. 6.—Application of Edgar Vaughan's hydraulic leather packings.

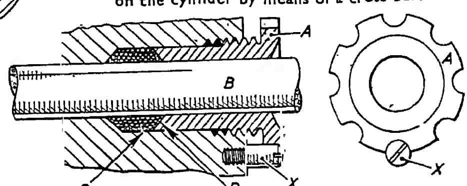


Fig. 5.—Showing a typical gland having opposing tapers to ensure leak-proof water-pump cylinders.

sufficient, or a semi-spherical contact, as at F and G. The idea is to allow the joints at E and D to take up their own bearing on the faces of the cylinder ports.

A gland joint or stuffing-box is often used in the case of a water-pump spindle. This is intended to allow free movement of the spindle without allowing water to leak through, even if the spindle wears slightly in its bearing.

Reverse Tapers.—Such a joint is shown in Fig. 5. The gland A fits (a running fit) round the pump spindle B and screws into the packing-chamber C. Its end is tapered inwards, and the end of the chamber C is similarly tapered in the reverse direction, so that packing wound around the spindle in the packing-chamber is forced down to the spindle and compressed against it to make a tight joint. Asbestos string soaked in hot tallow mixed with graphite is used to make the joint. This provides the necessary resistance to soaking by the water, and acts as a lubricant to the pump spindle and prevents wear. The wick from a tallow candle, similarly treated, also makes excellent packing.

When the gland A is screwed out along the spindle (the drive wheel or pulley having been removed), the packing (cotton or asbestos string) is wound round the spindle, though not tightly, and is pushed up by the gland, the plain end D of which exactly fits the packing-chamber. It should push up easily till the threads in the gland reach the thread in the pump case, and then further pressure to force the packing down on to the spindle is obtained by screwing the gland into the threads. To prevent the gland slacking off (a remote contingency), the gland is provided with semicircular recesses in its edge (as shown in the end view), and a screw, X, screwed into the pump case, engages with its head one of the semicircular recesses and locks the gland. Other means of locking are sometimes provided, but their operation will be clear and their object the same.

For cast-iron water mains a packing made of dried jute (sometimes oakum) is used. Jute has the advantage that it is free from oil and grease. Portland cement is used as a seal.

Jointing Materials.—It is always wise to use one of the many excellent commercial brands of packing material for flanged and faced joints. The material should be selected according to the purpose. It may be necessary to use one which is unaffected by oil, spirit, or other hydrocarbons. Metallic packing is entirely satisfactory, and it is made in block type, cone or locomotive, duplex, atmospheric duplex, and in other grades for use in low-pressure condensing cylinders. Ring packing is an improvement upon the original Bramah Ring. In this a flexible tongue is on the inside of the ring where a normal gland packing is required to fit, say, a moving rod or ram, and it is made in the form of a wedge which thickens up at the crown and furnishes the fulcrum for its movement.

Where it is necessary to use paper packing, tacky gold-size should be used on both sides of the paper.

Leather is now being used for packings in place of rubber, especially for hydraulic and pneumatic machinery. Designers should consult leather-packing manufacturers as to their requirements. Leather washers are available in all standard cup, flange, and U-types, as well as in washers and gaskets.

Leather manufacture and the moulding of hydraulic and pneumatic packings have progressed considerably. The belief must be dispelled that it is sufficient to requisition a leather of certain shape and size. It is most important that pressures and temperatures are stated, so that the type of leather required can be selected. Not only is the tannage different, but the subsequent processes of manufacturing the leathers with a suitable filler to resist, first, the type of medium—oil, air, or water—and the second, the operating temperatures and pressures.

The leather-packing manufacturer is always interested to know that the leathers are being housed correctly with proper clearances for swell. In the matter of replacing rubber seals with leather, an important point is take-up of initial pressure and method of holding the leather in position; packing the inside of a U-leather controls success or failure in this respect.

Both leather and rubber have their respective uses and limitations, advantages and disadvantages, but there are many instances where leather packings of suitable design and manufacture will replace rubber satisfactorily with marked improvement in durability.

Standard Atmosphere.—The table below gives the physical properties of the atmosphere at heights above sea-level in the region where aircraft flight is normal. Because flight conditions vary from day to day throughout the year, it is neces-

PHYSICAL PROPERTIES OF THE STANDARD ATMOSPHERE

Height in Feet	*Absolute Density* ρ *slugs/cu. ft.*	*Relative Density* $\sigma = \frac{\rho}{\rho_0}$	*Absolute Pressure* p *lb./ft.*^{2}	*Temperature* t *°C.*	*Speed of Sound* a *ft./sec.*	*Kinematic Viscosity* $\nu \times 10^4$ *ft.*^{2}*/sec.*
0	0·002378	1·0000	2116·2	15·00	1117	1·564
2,000	0·002242	0·9428	1967·7	11·04	1109	1·641
4,000	0·002112	0·8881	1827·7	7·08	1102	1·723
5,000	0·002049	0·8617	1760·8	5·10	1098	1·766
6,000	0·001988	0·8359	1696·0	3·12	1094	1·810
8,000	0·001869	0·7860	1571·9	− 0·84	1086	1·903
10,000	0·001756	0·7385	1455·4	− 4·80	1078	2·002
12,000	0·001649	0·6932	1345·9	− 8·76	1070	2·107
14,000	0·001546	0·6500	1243·2	− 12·72	1062	2·220
15,000	0·001497	0·6292	1194·3	− 14·70	1058	2·280
16,000	0·001448	0·6090	1147·0	− 16·68	1054	2·341
18,000	0·001355	0·5699	1056·9	− 20·64	1046	2·470
20,000	0·001267	0·5328	972·6	− 24·60	1037	2·608
22,000	0·001225	0·5150	932·5	− 26·58	1029	2·757
24,000	0·001104	0·4642	820·3	− 32·52	1021	2·915
25,000	0·001066	0·4481	785·3	− 34·50	1017	2·999
26,000	0·001029	0·4325	751·7	− 36·48	1012	3·087
28,000	0·000957	0·4025	687·9	− 40·44	1004	3·270
30,000	0·000890	0·3741	628·5	− 44·40	995	3·469
32,000	0·000826	0·3473	573·3	− 48·36	991	3·682
34,000	0·000766	0·3220	522·2	− 52·32	978	3·913
35,000	0·000737	0·3099	498·0	− 54·30	973	4·036
36,000	0·000709	0·2981	474·7	− 56·28	969	4·159
36,090	0·000707	0·2972	472·7	− 56·5	968	4·172
Tropopause						
Stratosphere						
38,000	0·000645	0·2711	431·2	Both temperature		4·573
40,000	0·000586	0·2463	391·8	and speed of		5·034
42,000	0·000532	0·2237	355·8	sound remain		5·542
44,000	0·000483	0·2032	323·2	constant at all		6·102
45,000	0·000460	0·1936	308·0	heights above		6·403
46,000	0·000439	0·1846	293·6	the tropopause		6·718
48,000	0·000399	0·1676	266·6	at values:		7·396
50,000	0·000362	0·1523	242·2	−56·5°C.	968 ft./sec.	8·141

Value of g 32·1726 ft./sec.^{2}

Speed of sound $a = (65{\cdot}80\sqrt{\text{absolute temp. °C.}})$ ft./sec.

also $a = \sqrt{\frac{\gamma p}{\rho}}$; γ = ratio of specific heats of air, assumed 1·403.

$$\nu = \frac{\mu}{\rho} = \frac{3{\cdot}059 \times 10^{-8}}{\rho} \cdot \frac{(\text{absolute temp. °C.})^{\frac{3}{2}}}{114 + \text{abs. temp. °C.}}$$

SUTHERLAND AND GOLDSTEIN.

sary for comparing the performance of aircraft to specify some standard to which day-to-day observations are corrected. The table is derived from the International Standard Atmosphere as defined in the Official Bulletin of the International Commission on Air Navigation.

Points to notice are the wide temperature range the aircraft components have to withstand, i.e. 15° C. to −56·5° C. In fact, it is freezing at any height above 8000 ft. For aircraft designed to operate at great heights it is important to ensure that materials with widely differing values of coefficient of expansion should not be used for the aircraft structure and the operating mechanism of the control surfaces (ailerons, elevators, and rudder)..

The density of the air varies considerably, and since the lift of the aircraft depends directly on the density it may be difficult to take off with heavy loads on an aerodrome situated on ground fairly high above sea-level. This density variation also adversely affects the aircraft performance in that the normally aspirated engine will suffer a loss of power with height due to the fact that the engine power is proportional to the *weight* of air burned. At 21,000 ft. the engine for the same revs. will develop approximately only half its ground-level value.

The viscosity of the air, i.e. friction of the air passing very close to the wing, decreases with height purely because the temperature is decreasing, but the kinematic viscosity, which is viscosity reduced to a weight of air basis, increases at great heights to some four or more times its value at sea-level. This alters the Reynolds number of the airflow over the aircraft.

Similarly the speed of sound decreases with height, again purely due to temperature decreasing. This becomes important on high-speed aircraft and is dealt with under Compressibility. An aircraft may experience trouble due to compressibility at a great height but when dived to a lower level may get out of trouble.

Prediction of Full-scale Results from Tests on Models.—Valuable information on the behaviour of a full-scale aircraft can be obtained before it is built by wind-tunnel tests of a model, and any particularly bad features of a design can be detected and remedied at an early stage in its design. It is also possible to test parts of the aircraft full scale in a tunnel to find the behaviour of particular modifications. The following article gives the important parameters it is necessary to comply with in order that the behaviour of the full-scale aircraft may be accurately predicted from the model tests.

The basic aerodynamic theory of the flow of fluid round bodies is based on the assumption that the fluid is frictionless and incompressible. Calculations based on this predict with fair accuracy the forces acting on a body, the velocity of air close to but not immediately touching the body (within say 2 in. of a body some 10 ft. long), and the normal pressure distribution round the body.

Air, however, is neither frictionless nor incompressible, and in most cases the effect of this is to modify the airflow round, and the aerodynamic forces acting upon, the body. The effect of friction of the air is normally confined to a region of air normal to the surface of the body varying from $\frac{1}{10,000}$ in. at the forward portion, to approximately 2 in. at the rear end[1] of a typical body, say, 10 ft. long. In this region, called the Boundary Layer, the air touching the body has zero velocity relative to the body, rising to the velocity of the main stream just outside this layer. On a wing, say, of 10-ft. chord at the position along the chord where the boundary layer is $\frac{1}{10}$ in. and the local velocity of air just outside the boundary layer relative to the body is, say, 300 m.p.h., the air has a mean velocity gradient of:

$$\frac{300 \times \frac{88}{60}}{\frac{1}{10} \Big/ 12} \ \frac{\text{ft./sec.}}{\text{ft.}} = 52{,}800 \text{ ft./sec./ft.}$$

The friction of air is defined by its viscosity, *the coefficient of viscosity* of a fluid being defined as the force required to move one of two parallel plates immersed

[1] Body considered at small incidence to relative wind.

in the fluid, each plate being of unit area, the two separated by unit distance, and the relative velocity between them also being of unit intensity. This coefficient is usually denoted by the letter μ. But since this coefficient is expressed per volume of fluid and the chief interest in aircraft performance is per mass of air, this coefficient is divided by the absolute density of air to give a coefficient called the coefficient of Kinematic Viscosity, i.e. coefficient of viscosity per unit mass of fluid. It is usually denoted by the letter ν. Thus :

$$\nu = \frac{\mu}{\rho} \quad \frac{\text{ft.}^2}{\text{sec.}}$$

Hence in the example given above and from the definition of coefficient of viscosity, the force acting per square foot of the wing opposing the air flow at the position considered at ground level, is given by :

$$\begin{aligned} F &= \text{Area} \times \mu \times \text{velocity gradient} \\ &= 1 \times 1{\cdot}564 \times 10^{-4} \times 0{\cdot}002378 \times 52800 \text{ ft.}^2 \left(\frac{\text{lb. sec.}}{\text{ft.}^2}\right) \frac{1}{\text{sec.}} \\ &= 0{\cdot}02 \text{ lb.} \end{aligned}$$

Thus drag of aerofoil due to friction at this position is $\frac{F}{\text{unit area}}$

$$= 0{\cdot}02 \text{ lb./ft}^2.$$

The example is approximate and is given purely to demonstrate the meaning of viscosity.

If the basic aerodynamic theory is modified to include the effects of friction, then the aerodynamic force acting on a body in steady motion relative to the air is given by the formula :

$$F = \rho l^2 V^2 \times k \times f_1\left(\frac{Vl}{\nu}\right) \text{ lb.}$$

where F = Force in lb.
ρ = Density of air slug/ft.^{3}.
l = Some arbitrary dimension on the body, usually its length parallel to the airstream (ft.).
V = Velocity of air relative to body (ft./sec.).
k = Coefficient, dimensionless, depending only on the shape of the body and its attitude to the undisturbed airstream.
$f_1\left(\frac{Vl}{\mu}\right)$ = Some function of the quantity $\frac{Vl}{\nu}$.

The quantity $\frac{Vl}{\nu}$ is called the *Reynolds number.* It is a dimensionless coefficient which takes account of friction of the air, and it has been found from experiment that the type of airflow over a body in the immediate vicinity of the surface of the body depends very much on the value of $\left(\frac{Vl}{\nu}\right)$, so that when predicting full-scale behaviour from model tests it is important that the type of airflow over both is similar, and for this reason the model tests should be carried out at a Reynolds number as close to that at full scale as it is possible to obtain.

The above effects of friction are contained in the very small region of air adjacent to the body, i.e. in the boundary layer. Outside this region the air flowing past the body undergoes changes of pressure and velocity to allow for the passage of the body, usually the air speeds up and the pressure relative to the undisturbed stream is lowered. This lowering of pressure causes the air to some extent (very small below speeds of 300 m.p.h. at ground level) to expand. This expanded air occupies more space than if the air were incompressible, so that the airflow pattern is modified accordingly. When the speed of sound is reached, the air ceases to follow the previous relation of pressure dropping with increased velocity, and the aerodynamic theory based on this ceases to apply. Therefore to ascertain how near the conditions of airflow round the body are to this state of affairs, the conception is introduced of Mach number.

Mach number is purely the ratio $\frac{\text{speed of undisturbed air}}{\text{speed of sound}} = \frac{V}{a}$, and the closer this number approaches to the value 1·0 the more it is appreciated that the basic aerodynamic theory of incompressible fluid ceases to apply. The prediction of the behaviour full scale from model tests therefore, where this condition applies, should be based on similar types of airflow, i.e. on similar values of Mach number, and in this case the aerodynamic force acting on a body may be expressed in the form :

$$F = \rho l^2 V^2 \times k \times f_2\left(\frac{V}{a}\right)$$

where $f_2\left(\frac{V}{a}\right)$ is some unknown function of the properties of the airflow, but can be eliminated by testing models and full scale at the same value of $\left(\frac{V}{a}\right)$.

For regions of $\left(\frac{V}{a}\right)$ less than 1 but greater than 0·7 the Reynolds number effect, i.e. friction, is small compared with the effects of compressibility, whilst below Mach numbers of about 0·6 the effects of compressibility can in most cases be ignored compared with the effects of friction.

Thus it is seen that prediction of full-scale performance from model tests can be made only if the types of fluid flow round the bodies are similar. The problem always is to assess the effects of various parameters on the fluid flow and maintain these conditions constant for model and full scale. Another effect, for instance, occurs when flying-boat hulls are water borne. Here the hull displaces water, the displaced water forming waves in which a mass of water is lifted relative to its undisturbed state against gravitational force. The force acting in this case may be expressed as :

$$F = \rho l^2 V^2 \times k \times f_3\left(\frac{V^2}{lg}\right).$$

This effect may be eliminated by making $\frac{V^2}{lg}$ the same for both model and full scale. The model will then give the same type of wave formation as full scale when :

$$V_{\text{model}} = V_{\text{full scale}} \sqrt{\frac{l_{\text{model}}}{l_{\text{full scale}}}}.$$

This condition to be satisfied is commonly known as Froude's Law of corresponding speeds.

Notice that the condition for the friction of the hull, i.e. $\left(\frac{Vl}{\nu}\right)_{\text{water}}$ cannot be satisfied at the same time as the water wave making resistance. To predict full-scale effects from models is therefore difficult for flying-boats, the usual practice being to test the model at the corresponding speed and to superimpose the water-friction resistance and air resistance by calculation on these results.

Similarly for aircraft it is impossible to fulfil the two conditions $\left(\frac{Vl}{\nu}\right)$ and $\left(\frac{V}{a}\right)$ at the same time for both model and full scale. Results are generally obtained for one or the other condition only, since it is found by experience that, depending on the type and speed of the aircraft, one of the two effects is usually negligible in comparison with the other.

Aerofoil Characteristics.—An aircraft is supported by wings which are specially designed lifting surfaces (aerofoils) in which the drag is a small fraction of the vertical lift.

Fig. 1 shows the forces acting on an aerofoil. The resultant force, R, is resolved along and normal to the direction of flight, giving the drag, D, and lift, L, respectively.

If S is area of wing (ft.^{2})
ρ density of air (slug/ft.^{3})
V velocity of wind (ft./sec.)

then lift $L = C_L \cdot \frac{1}{2}\rho S V^2$
drag $D = C_D \cdot \frac{1}{2}\rho S V^2$
moment $M = C_M \cdot c \cdot \frac{1}{2}\rho S V^2$.

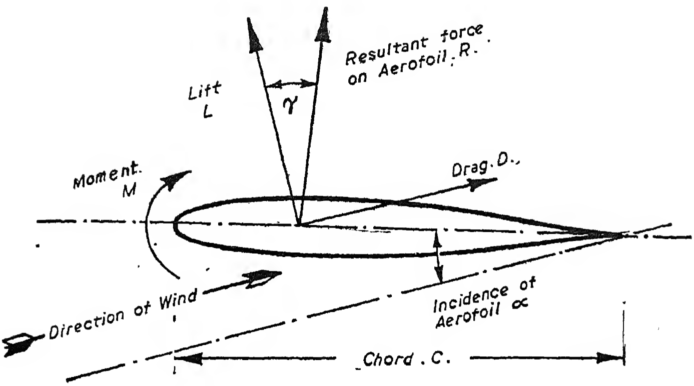


Fig. 1.—Forces acting on an aerofoil.

C_L, C_D, and C_M are defined respectively as the lift, drag, and moment coefficients, and are non-dimensional properties of the aerofoil section and depend upon the angle of incidence α, that is the angle of attack of the aerofoil relative to the air-stream.

The moment coefficient is usually referred to the quarter-chord position, exceptions to this rule being always stated when this is not so.

Typical values of C_L, C_D, and C_M for one particular aerofoil, Clark YH, known for its small moment coefficient, are given in the table below.

These values differ for different aerofoils, and for the same aerofoil vary with Reynolds number and Mach number.

A small moment coefficient is desirable since the moment from the wings has to be balanced by the tailplane and elevator, and if this moment is large it imposes large tailplane loads which, in turn, impose large structural loads on the fuselage, thus making the aircraft heavy structurally and difficult to control over a wide range of attitudes.

ORDINATES OF AEROFOIL N.A.C.A. 23012

L.E. radius = 1·58. All values expressed as percentage of chord.

Distance from L.E.	*Upper Surface*	*Lower Surface*	*Distance from L.E.*	*Upper Surface*	*Lower Surface*
0	0	0	30	7·55	— 4·46
1·25	2·67	— 1·23	40	7·14	— 4·48
2·5	3·61	— 1·71	50	6·41	— 4·17
5·0	4·91	— 2·26	60	5·47	— 3·67
7·5	5·80	— 2·61	70	4·36	— 3·00
10	6·43	— 2·92	80	3·08	— 2·16
15	7·19	— 3·50	90	1·68	— 1·23
20	7·50	— 3·97	95	0·92	— 0·70
25	7·60	— 4·28	100	0	0

Properties of Aerofoils.—It is now possible to design aerofoils to give particular characteristics required whether for flight or structural reasons, but the calculations are very involved and are of particular interest to so few people in the country that they are beyond the scope of this work. It is intended here

AEROFOIL CHARACTERISTICS OF N.A.C.A. 23012[1]

Size of aerofoil . . . . . span 36 ft., chord 6 ft.
at $R = 4\cdot4 \times 10^6$ zero lift;
$R = 4\cdot1 \times 10^6$ max. lift.

α_∞	α_6	C_L	C_D	C_{D_0}	$C_{max.}$*
− 3·2	− 3·9	− 0·2	0·0112	0·0090	− 0·008
− 2·2	− 2·5	− 0·1	0·0090	0·0084	− 0·009
− 1·2	− 1·2	0	0·0079	0·0079	− 0·009
− 0·2	+ 0·2	+ 0·1	0·0079	0·0073	− 0·008
0·8	1·6	0·2	0·0090	0·0068	− 0·008
1·8	3·0	0·3	0·0120	0·0070	− 0·007
2·8	4·3	0·4	0·0167	0·0078	− 0·007
3·8	5·7	0·5	0·0228	0·0089	− 0·007
4·9	7·0	0·6	0·0298	0·0097	− 0·006
5·9	8·3	0·7	0·0378	0·0105	− 0·007
6·9	9·7	0·8	0·0467	0·0110	− 0·007
7·9	11·0	0·9	0·0565	0·0114	− 0·005
8·9	12·3	1·0	0·0673	0·0116	− 0·007
9·8	13·7	1·1	0·0796	0·0121	− 0·006
10·8	15·1	1·2	0·0928	—	− 0·008
11·8	16·4	1·3	0·108	—	− 0·009
13·0	17·9	1·4	0·126	—	− 0·009
13·9	19·2	1·46	0·144	—	− 0·010
15·4	19·6	1·2	0·197	—	− 0·037
17·1	21·0	1·1	0·229	—	− 0·067

α_∞ = Angle of attack for infinite aerofoil.
α_6 = Angle of attack for aerofoil of aspect ratio 6.
C_L and C_D = Values of coefficient for aspect ratio 6.
C_{D_0} = Value of drag coefficient for infinite aspect ratio.

* About "Aerodynamic Centre," 0·014 chord forward of, and 0·049 chord above quarter-chord position with chord at 0°.

to give briefly the important parameters, their effects and the values for a series of aerofoils which should cover the needs of most practical aeronautical engineers.

The *chord* of an aerofoil may be defined as the length of the projection of the aerofoil on a flat plane touching the bottom surface near the nose and trailing edges. This is most convenient for defining wing areas and centre of pressure positions when considering the overall equilibrium of the aircraft, but in aerofoil theory a more concise definition is required. Basically the aerofoil section consists of a *mean line* which may or may not be curved, i.e. have *camber*, and a fairing for this mean line disposed equally distant on either side of it and forming the top and bottom profiles of the aerofoil. The chord is then the length of the mean line from its extreme forward (leading-edge) to its extreme aft (trailing-edge) position.

The camber is then the distance of the mean line from a line joining these two positions, and it is usually specified that this camber occurs at a certain position of the chord. As stated above, the mean line is faired (or streamlined), and the total distance from the top to the bottom surface of the aerofoil at any position on the chord is called the thickness of the aerofoil and is always expressed as a fraction of the chord. The position of the maximum thickness is usually specified as some percentage of the chord aft of the leading edge.

[1] N.A.C.A. Report No. 530.

Effects of Camber and Thickness on Properties of Aerofoil Sections.—Camber determines largely :

(1) Chordwise distribution of lift.
(2) Lift coefficient for which profile drag is a minimum.
(3) Pitching moment.
(4) Angle of zero lift.
(5) Maximum lift coefficient.
(6) Drag.

Thickness determines largely the drag and the behaviour at the stall. Leading-edge radius and trailing-edge angle chiefly affect the drag. The shape of a mean line especially near the trailing edge affects the pitching moment considerably. The C_{M_0} may be reduced either by making the mean-line reflex near the trailing edge or by positioning the maximum camber of this line fairly far forward ($0{\cdot}15c$).

The student of this subject is advised to obtain a copy of N.A.C.A. Report No. 460—characteristics of seventy-eight related aerofoils in which are the results of an extensive series of tests to determine the various effects referred to above.

Briefly the main conclusions of the report are as follows :

(A) Variation of aerodynamic characteristics with thickness ratio :

(1) The minimum profile drag varies with thickness approximately in accordance with the expression :

$$C_{D_0\ \text{min.}} = k + 0{\cdot}0056 + 0{\cdot}01t + 0{\cdot}1t^2$$

where the value of k depends upon the camber and t is the ratio of the maximum thickness to the chord.

(2) The lift coefficient corresponding to the minimum profile drag coefficient approaches zero as the thickness is increased.

(3) The magnitude of the moment at zero lift decreases with increased thickness.

(4) The ratio of maximum lift to the minimum profile drag is highest for aerofoils of medium thickness ratios (9–12 per cent.).

(5) The greatest instability of the airflow at maximum lift is encountered with the moderately thick, low-cambered sections.

(B) Variation of aerodynamic characteristics with camber.

(1) The minimum profile drag increases with increased camber and also with a rearward movement of the camber.

(2) *The lift coefficient corresponding to the minimum profile drag coefficient increases with the camber*, and for the highly cambered sections a definite increase accompanies a forward movement of the camber.

(3) The moment at zero lift is nearly proportional to the camber.

(4) The ratio of maximum lift to the minimum profile drag tends to decrease with increased camber (above 2 per cent. of the chord) and with a rearward movement of the camber (for the highly cambered sections).

(5) The maximum lift increases with increased camber, the increase being more rapid as the camber moves forward or back from a point near the $0{\cdot}3c$ position.

(6) Greater stability of air flow at maximum lift is obtained with increased camber if the camber is in the normal positions ($0{\cdot}3c$ to $0{\cdot}5c$).

Since the aerofoil-section characteristics depend to so large an extent on thickness and camber, the Americans have adopted the four-digit system of designating an aerofoil. Thus N.A.C.A. 2312 section has a maximum camber (first digit) of 2 per cent. of the mean chord. The position of the maximum camber is 0·3 (second digit) of the mean chord aft of the leading edge, and the maximum thickness (last two digits) is 12 per cent. of the mean chord. This maximum thickness for all the four-digits series of aerofoils is at 30 per cent. of the mean chord.

Basic ordinates of N.A.C.A. family aerofoils (per cent. of chord) derived from two fairly efficient types, Clark Y and Gottingen 398, are as follows :

Aerofoil approximately 20 per cent. thick. For other thicknesses, t per cent., factor in ratio $\frac{t}{20}$.

Station per cent. of Chord	Ordinate	Station per cent. of Chord	Ordinate
0	0	30	10·003
1·25	3·157	40	9·672
2·5	4·358	50	8·823
5·0	5·925	60	7·606
7·5	7·000	70	6·107
10	7·805	80	4·372
15	8·909	90	2·413
20	9·563	95	1·344
25	9·902	100	0·210
	L.E. radius 4·40		

Important characteristics of N.A.C.A. series of aerofoil sections tabulated below were derived from wind-tunnel tests at a Reynolds number approximately 3×10^6.

These tables are given as representative of most types of aerofoil and form a useful basis for comparing other types.

Section Characteristics

Aerofoil	$C_{L_{max.}}$	α_0 at $C_{L_{max.}}$ (*deg.*)	α_{L0} (*deg.*)	$a_0 = \frac{\delta C_L}{\delta \alpha_0}$ (*per deg.*)	$C_{D0_{min.}}$	$\frac{C_{L_{max.}}}{C_{D0_{min.}}}$	C_{M_0}
0006	0·88	13	−0·1	0·102	0·0065	135	−0·002
0009	1·27	14	0·0	0·101	0·0074	172	−0·003
0012	1·53	17	0·0	0·101	0·0083	184	−0·002
0015	1·53	17	0·0	0·100	0·0093	164	0·000
0018	1·49	17	0·0	0·098	0·0108	138	−0·002
0021	1·38	17	−0·1	0·094	0·0120	115	−0·001
0025	1·20	16	0·0	0·089	0·0143	84	−0·003
2212	1·60	16	−1·8	0·103	0·0087	184	−0·029
2306	1·04	11	−1·8	0·104	0·0073	142	−0·036
2309	1·51	15	−2·0	0·103	0·0083	182	−0·036
2312	1·61	16	−1·9	0·101	0·0089	181	−0·038
2315	1·54	15	−1·7	0·102	0·0100	154	−0·034
2406	1·01	13	−1·7	0·103	0·0070	144	−0·039
2409	1·51	14	−1·7	0·103	0·0080	189	−0·044
2412	1·62	17	−1·8	0·101	0·0085	190	−0·044
2415	1·55	16	−1·7	0·101	0·0099	156	−0·040
2418	1·43	15	−1·9	0·098	0·0112	128	−0·037
2421	1·35	16	−1·7	0·097	0·0127	106	−0·036
2506	1·03	15	−2·0	0·103	0·0073	141	−0·048
2509	1·38	13	−2·0	0·102	0·0081	170	−0·052
2512	1·62	17	−2·1	0·102	0·0088	184	−0·054
2515	1·53	16	−2·0	0·099	0·0103	148	−0·049
2518	1·48	16	−2·0	0·096	0·0112	132	−0·047
2521	1·38	16	−1·8	0·095	0·0126	109	−0·043
2612	1·66	17	−2·3	0·100	0·0089	187	−0·060
2712	1·68	17	−2·6	0·100	0·0090	187	−0·075

Aerofoil	Section Characteristics						
	$C_{L_{max.}}$	α_0 at $C_{L_{max.}}$ (*deg.*)	α_{L_0} (*deg.*)	$a_0 = \frac{\delta C_L}{\delta \alpha_0}$ (*per deg.*)	$C_{D_{0_{min.}}}$	$\frac{C_{L_{max.}}}{C_{D_{0_{min.}}}}$	C_{M_0}
4212	1·71	16	−3·4	0·102	0·0092	186	−0·059
4306	1·20	10	−3·8	0·103	0·0080	150	−0·075
4309	1·60	15	−3·6	0·103	0·0089	180	−0·073
4312	1·63	16	−3·9	0·100	0·0095	172	−0·075
4315	1·56	15	−3·6	0·103	0·0107	146	−0·068
4318	1·46	14	−3·5	0·099	0·0119	123	−0·065
4321	1·29	15	−3·6	0·095	0·0134	96	−0·057
4406	1·23	10	−3·9	0·104	0·0076	162	−0·087
4409	1·60	15	−3·6	0·103	0·0086	186	−0·086
4412	1·65	16	−3·9	0·100	0·0092	179	−0·089
4415	1·57	15	−3·8	0·101	0·0105	150	−0·083
4418	1·47	17	−3·7	0·096	0·0116	127	−0·078
4421	1·37	19	−3·4	0·093	0·0132	104	−0·071
4506	1·15	13	−4·3	0·104	0·0087	132	−0·109
4509	1·56	13	−4·1	0·103	0·0093	168	−0·106
4512	1·69	17	−4·2	0·097	0·0095	178	−0·105
4515	1·62	17	−4·1	0·101	0·0113	143	−0·097
4518	1·54	17	−3·9	0·096	0·0125	123	−0·094
4521	1·46	19	−3·4	0·095	0·0138	106	−0·082
4612	1·76	17	−4·6	0·098	0·0099	178	−0·124
4712	1·82	18	−5·0	0·097	0·0104	175	−0·143
6212	1·75	14	−5·2	0·100	0·0101	173	−0·087
6306	1·54	12	−5·2	0·105	0·0092	167	−0·109
6309	1·67	13	−5·4	0·104	0·0101	165	−0·110
6312	1·66	14	−5·5	0·101	0·0102	163	−0·110
6315	1·55	13	−5·4	0·101	0·0120	129	−0·105
6318	1·43	13	−5·2	0·098	0·0130	110	−0·097
6321	1·37	17	−5·2	0·096	0·0144	95	−0·090
6406	1·43	9	−5·6	0·104	0·0086	166	−0·129
6409	1·68	15	−5·9	0·101	0·0094	179	−0·133
6412	1·67	15	−5·7	0·101	0·0104	160	−0·132
6415	1·59	17	−5·7	0·099	0·0120	133	−0·125
6418	1·51	18	−5·7	0·099	0·0132	114	−0·118
6421	1·41	18	−5·2	0·096	0·0146	97	−0·110
6506	1·29	10	−6·3	0·101	0·0093	139	−0·159
6509	1·71	15	−6·3	0·103	0·0100	171	−0·158
6512	1·75	17	−6·2	0·101	0·0106	165	−0·159
6515	1·67	18	−6·0	0·099	0·0127	132	−0·150
6518	1·61	18	−5·7	0·095	0·0141	114	−0·139
6521	1·49	19	−5·3	0·094	0·0154	97	−0·129
6612	1·83	17	−6·6	0·099	0·0114	161	−0·186
6712	1·95	18	−7·0	0·097	0·0126	155	−0·206

Aerofoil	Wing Characteristics A.R.6			Structural Characteristics				
	$C_{D_{min.}}$	$\frac{L}{D}$ max.	C_L at $\frac{L}{D}$ max.	Thickness at 0·15 Chord (Per cent. Chord)	Thickness at 0·65 Chord (Per cent. Chord)	c.p. at Maximum Forward Position (Per cent. Chord)	$\frac{1}{4}C_{L_{max.}}$ (Per cent. Chord)	$\left(C/B\right)_0$
0006	0·0065	23·8	0·31	5·35	4·13	25	25	−0·082
0009	0·0074	22·9	0·36	8·02	6·20	25	25	−0·213
0012	0·0083	22·2	0·37	10·69	8·27	25	25	−0·285
0015	0·0093	21·2	0·40	13·36	10·33	25	24	−0·279
0018	0·0108	19·8	0·40	16·04	12·40	24	24	−0·285
0021	0·0120	18·5	0·44	18·71	14·46	23	23	−0·270
0025	0·0143	16·5	0·47	22·27	17·22	23	23	−0·233
2212	0·0088	22·4	0·40	10·69	8·25	27	32	−0·262
2306	0·0075	23·9	0·33	5·36	4·14	29	38	−0·130
2309	0·0085	22·9	0·39	8·04	6·21	28	34	−0·236
2312	0·0090	22·1	0·39	10·71	8·27	27	34	−0·268
2315	0·0100	20·5	0·41	13·38	10·36	27	34	−0·251
2406	0·0074	24·9	0·32	5·34	4·14	29	40	−0·103
2409	0·0082	23·1	0·36	8·02	6·20	28	36	−0·242
2412	0·0087	22·5	0·39	10·71	8·27	28	35	−0·274
2415	0·0100	20·8	0·40	13·39	10·34	28	35	−0·262
2418	0·0113	19·4	0·42	16·08	12·39	27	34	−0·238
2421	0·0128	17·9	0·43	18·75	14·46	27	34	−0·229
2506	0·0076	24·2	0·36	5·36	4·13	30	44	−0·116
2509	0·0083	22·9	0·37	8·04	6·21	29	40	−0·207
2512	0·0091	22·3	0·39	10·7	8·27	28	37	−0·270
2515	0·0104	20·4	0·41	13·38	10·33	28	37	−0·255
2518	0·0113	19·1	0·42	16·07	12·41	28	36	−0·255
2521	0·0126	17·7	0·44	18·72	14·47	28	36	−0·233
2612	0·0091	22·1	0·38	10·70	8·26	28	38	−0·274
2712	0·0093	22·0	0·38	10·69	8·25	29	41	−0·272
4212	0·0100	22·1	0·40	10·70	8·27	29	38	−0·260
4306	0·0094	23·7	0·38	5·40	4·14	31	49	−0·141
4309	0·0094	22·3	0·39	9·09	6·21	29	43	−0·236
4312	0·0100	21·7	0·40	10·77	8·27	30	43	−0·236
4315	0·0108	20·2	0·42	13·47	10·34	29	42	−0·233
4318	0·0121	19·0	0·43	16·14	12·41	29	41	−0·225
4321	0·0134	17·4	0·45	18·81	14·46	29	41	−0·196
4406	0·0089	24·2	0·38	5·40	4·16	32	53	−0·144
4409	0·0092	22·9	0·40	8·07	6·21	31	46	−0·242
4412	0·0096	22·1	0·40	10·77	8·28	31	45	−0·253
4415	0·0108	20·5	0·42	13·45	10·34	30	45	−0·242
4418	0·0120	19·2	0·43	16·15	12·40	30	44	−0·231
4421	0·0133	17·7	0·44	18·79	14·48	30	44	−0·222
4506	0·0098	22·7	0·40	5·38	4·14	33	63	−0·103
4509	0·0099	22·0	0·40	8·08	6·21	32	52	−0·229
4512	0·0099	21·7	0·40	10·74	8·28	31	49	−0·262
4515	0·0116	19·6	0·43	13·44	10·35	31	48	−0·253
4518	0·0126	18·4	0·43	16·14	12·41	31	48	−0·244
4521	0·0138	17·2	0·45	18·80	14·47	30	46	−0·244
4612	0·0105	21·1	0·41	10·73	8·27	31	52	−0·275
4712	0·0110	20·7	0·41	10·74	8·26	32	55	−0·290
6212	0·0117	20·9	0·44	10·78	8·29	30	44	−0·240

	Wing Characteristics A.R.6			*Structural Characteristics*				
Aerofoil	$C_{D_{min.}}$	$\frac{L}{D}max.$	C_L at $\frac{L}{D}max.$	*Thickness at* 0·15 *Chord* (*Per cent. Chord*)	*Thickness at* 0·65 *Chord* (*Per cent. Chord*)	*c.p. at Maximum Forward Position* (*Per cent. Chord*)	*c.p. at* $\frac{1}{4}C_{L_{max.}}$ (*Per cent. Chord*)	$^{4}\left(C/B\right)_0$
6306	0·0177	21·6	0·42	5·47	4·15	32	54	−0·187
6309	0·0116	21·1	0·42	8·18	6·23	32	51	−0·213
6312	0·0115	20·9	0·44	10·86	8·29	31	51	−0·218
6315	0·0125	19·3	0·45	13·58	10·37	32	52	−0·214
6318	0·0133	18·4	0·45	16·27	12·44	32	50	−0·209
6321	0·0145	17·0	0·47	18·92	14·51	31	50	−0·214
6406	0·0139	22·6	0·42	5·42	4·15	34	62	−0·157
6409	0·0113	21·6	0·42	8·14	6·21	33	57	−0·225
6412	0·0117	20·8	0·42	10·85	8·29	33	56	−0·242
6415	0·0127	19·2	0·45	13·55	10·36	33	56	−0·238
6418	0·0137	18·1	0·45	16·28	12·43	33	55	−0·231
6421	0·0148	16·9	0·46	18·96	14·50	33	54	−0·224
6506	0·0122	21·6	0·42	5·41	4·14	35	74	−0·121
6509	0·0119	21·0	0·43	8·14	6·21	34	62	−0·236
6512	0·0119	20·6	0·42	10·84	8·30	33	60	−0·257
6515	0·0134	18·7	0·44	13·53	10·36	33	59	−0·253
6518	0·0142	17·4	0·46	16·22	12·44	33	58	−0·251
6521	0·0155	16·0	0·47	18·92	14·49	33	57	−0·233
6612	0·0124	19·8	0·43	10·80	8·28	33	64	−0·270
6712	0·0135	18·6	0·45	10·76	8·27	34	65	−0·289

(1) Based on $\frac{1}{4}C_{L_{max.}}$
(2) Based on straight portion of lift curve extended.
(3) Based on straight portion of moment curve extended.
(4) Ratio of the chord component to the beam component of the air forces to be used for the high angle of attack condition if the plane of the drag truss is parallel to the aerofoil chord. C/B should be calculated when the plane of the drag truss is not parallel to the chord.

$$C/B = \frac{(C/B)_0 + k}{1 - k(C/B)_0}$$

where k is the slope of the drag truss with respect to the aerofoil chord.

Effect of Flaps and other Lift-increasing Devices.—The landing speed of the aircraft (given good control at slow speeds) will be the stalling speed on the glide, and is given by the equation:

$$V_{m.p.h.} = 19{\cdot}8\sqrt{\frac{\text{wing loading lb./ft.}^2}{C_{L_{max.}} \times \text{relative air density}}}.$$

The $C_{L_{max.}}$ will be the overall value for the aircraft, including the tail lift and body lift (if any). It can only be determined with accuracy from full-scale tests, but the great majority of the lift comes from the wings. The maximum lift coefficient of the wings is usually artificially increased by the fitting of slots, flaps, or a combination of these.

Typical values of the various lift-increasing devices are given below.

The problem may be looked at from another angle. If, for instance, a maximum

landing speed of aircraft is specified, then the greater $C_{L_{max.}}$ with flaps allows of greater wing loading.

$$\text{Wing loading} = \frac{\text{Weight of aircraft}}{\text{Wing surface}}$$

and hence wing surface can be reduced, thus decreasing drag and increasing maximum speed.

If the wing loadings are identical, the wings with the highest $C_{L_{max.}}$ without flaps give the most manœuvrable aircraft. Consider speed of turn V constant for two aircraft. Then lift $L = C_L \cdot \frac{1}{2}\rho SV^2$ and the higher C_L the more L and hence greater acceleration for same wing loading. Maximum L occurs when C_L is a maximum. Hence aerofoils with camber should be used, since it is not advisable to use flaps at high speeds owing to their adverse pitching moments and increased drag, both of which affect the aircraft stability too much, besides the difficult structural problem of providing enough strength. But whilst it is useful to have the high $C_{L_{max.}}$ of the unflapped aerofoil, the section would in practice never be chosen for this property alone. Again, too, it must be pointed out that the effects of flaps apply in general to all normal aerofoils since the theoretical effect of the flap is to increase the camber of the aerofoil, the chord of the aerofoil in this case being the basic section plus the flap.

Typical values of $C_{L_{max.}}$ are 1·3, but the value varies considerably with Reynolds number, e.g. Clark YH section has a $C_{L_{max.}} = 1{\cdot}2$ at $R = 1 \times 10^6$ and 1·6 at $R = 8 \times 10^6$.

Although slots give improved $C_{L_{max.}}$, the structural difficulty of ensuring a flush leading edge to the aerofoil when fitted precludes their use on really high-speed low-drag aerofoils. This is shown up best in the $\frac{C_{L_{max.}}}{C_{D_{min.}}}$ column. For structural economy it is best to have as much continuous fixed aerofoil contour as possible from the leading edge to about 70 per cent. of the chord.

When all points are included, both structural and aerodynamic, the best practical compromise is probably confined to Fowler flap, split flap, or plain trailing-edge flap.

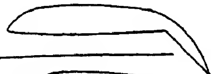
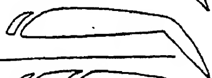
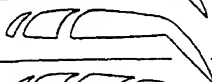
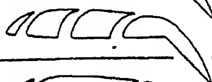
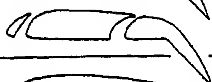
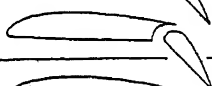
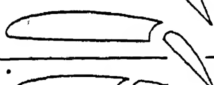
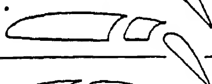
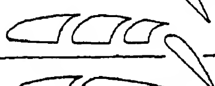
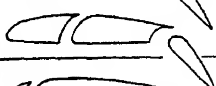
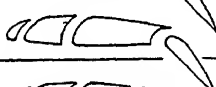
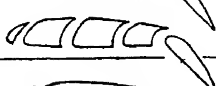
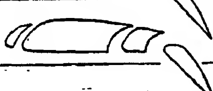
The advantages to be gained from the use of Fowler flaps may be either to reduce the landing speed by as much as 66 per cent. of the unflapped wing or, keeping the landing speed and gross weight the same, the original wing area may be reduced by 40 per cent. and the maximum speed of the aircraft increased by approximately 5 per cent.

Ordinates of Clark Y Aerofoil

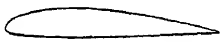
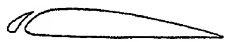
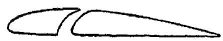
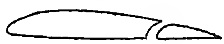
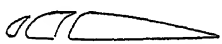
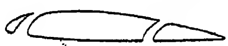
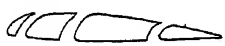
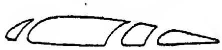
(L.E. radius 1·50. All values expressed as a percentage of the chord.)

Station	*Upper*	*Lower*	*Station*	*Upper*	*Lower*
0	3·50	3·50	40	11·40	0
1·25	5·45	1·93	50	10·52	0
2·50	6·50	1·47	60	9·15	0
5·00	7·90	0·93	70	7·35	0
7·5	8·85	0·63	80	5·22	0
10	9·60	0·42	90	2·80	0
15	10·69	0·15	95	1·49	0
20	11·36	0·03	100	0·12	0
30	11·70	0			

AERODYNAMIC CHARACTERISTICS OF A CLARK Y WING WITH MULTIPLE FIXED SLOTS AND A SLOTTED FLAP DOWN 45°

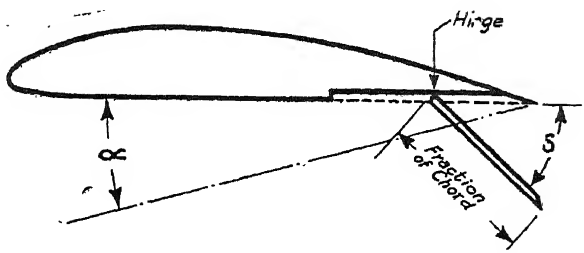
Slot Combination	$C_{L_{max.}}$	$C_{D_{min.}}$	$\frac{C_{L_{max.}}}{C_{D_{min.}}}$	α at $C_{L_{max.}}$
	1·950	0·0152	128·2	12°
	2·182	0·0240	91·0	19°
	2·235	0·0278	80·3	20°
	2·200	0·0340	64·7	21°
	2·210	0·0270	81·8	20°
	1·980	0·0164	120·5	12°
	1·770	0·0164	108·0	14°
	2·442	0·0208	117·5	16°
	2·500	0·0258	96·8	18°
	2·185	0·0214	102·0	18°
	2·261	0·0243	93·2	19°
	2·320	0·0319	72·7	20°
	2·535	0·0363	69·8	20°
	2·600	0·0298	87·3	20°
	2·035	0·0298	68·3	21°

Aerodynamic Characteristics of a Clark Y Wing with Multiple Fixed Slots

Slot Combination	$C_{L_{max.}}$	$C_{D_{min.}}$	$\frac{C_{L_{max.}}}{C_{D_{min.}}}$	α at $C_{L_{max.}}$
	1·291	0·0152	85·0	15°
	1·772	0·0240	73·8	24°
	1·596	0·0199	80·3	21°
	1·548	0·0188	82·3	19°
	1·440	0·0164	87·8	17°
	1·902	0·0278	68·3	24°
	1·881	0·0270	69·7	24°
	1·813	0·0243	74·6	23°
	1·930	0·0340	56·8	25°
	1·885	0·0319	59·2	24°
	1·885	0·0363	51·9	25°
	1·850	0·0298	62·1	24°
	1·692	0·0228	74·2	22°
	1·672	0·0214	78·2	22°
	1·510	0·0208	72·6	19°
	1·662	0·0258	64·4	22°

Split Flaps

(From N.A.C.A. T.N.422.)



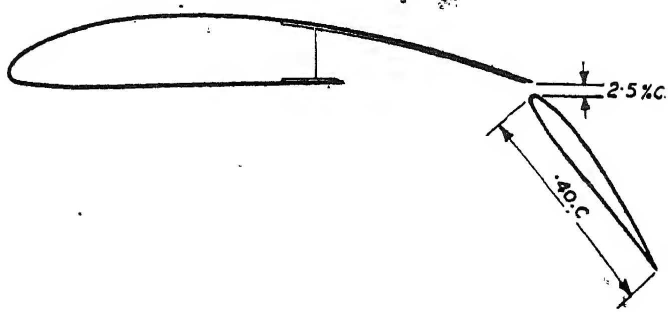
$C^1_{D_{min.}}$ = 0·0156 is value for flap fully retracted.

Position of Hinge Per cent.	*Length of Flap Per cent.*	α°	δ	$C_{L_{max.}}$	$C^1_{D_{min.}}$	$\frac{C_{L_{max.}}}{C_{D_{min.}}}$
80	20	14° (approx.)	0	1·28	See above	
			15	1·6		103
			30	1·88		120
			45	2·09		134
			60	2·11		135
			75	2·11		135
70	30	14°	15	1·75		112
			30	1·94		124
			45	2·10		134
			60	2·27		145
			75	2·28		146
60	40	14°	15	1·73		111
			30	2·10		134
			45	2·14		137
			60	2·16		138
			75	2·16		138
100	40	12½° (approx.)	15	2·05		131
			30	2·28		146
			45	2·40*		154
			60	2·40		154

* Directly comparable with Fowler flap.

All values quoted in the tables are at Reynolds No. 609,000 and wing Aspect Ratio 6.

FOWLER FLAPS
(From N.A.C.A. T.N.419.)



Position of Hinge Per cent.	*Length of Flap Per cent.*	$\alpha°$	δ	$C_{L_{max.}}$	$C^1{}_{D_{min.}}$	$\frac{C_{L_{max.}}}{C_{D_{min.}}}$
100	40	15°	40	3·17	0·0156	203

Aircraft Drag.—In assessing the performance of an aircraft it is essential to know the total drag. An approximate but fairly reliable method of assessing the overall drag is given at the end of this section, but for design purposes it is required to know the values for each component, i.e. wings, fuselage, etc., and the effects of such excrescences as wireless masts, aerials, exhaust pipes, etc. With this knowledge one is able to concentrate on items which are not good and to improve the design accordingly.

Generally the drag of items may be quoted at so many pounds at 100 ft./sec., or more usually nowadays refer the drags to the wing area. The total drag is then $\frac{1}{2}\rho SV^2 \times$ coefficient of drag of item considered, where S is the gross wing area and V the local velocity of the air over that particular item.

The various types of drag are classified according to their origin, and are as follows:

(1) Induced drag.
(2) Profile drag (form and surface-friction drag).
(3) Interference drag.
(4) Parasite drag.

Of these types the induced drag on an aircraft is inevitable, due to the fact that the wing has a finite span. It can, however, be reduced by increasing the wing aspect ratio and using an elliptic plan form. This is discussed in more detail below.

Profile drag consists of two components—form drag and surface-friction drag. Form drag is unimportant for streamline bodies (i.e. aerofoils) at relatively low speeds (Mach number $< 0{\cdot}5$), but it becomes a major item as the speed of sound is approached and the surface-friction drag then becomes unimportant. When interference and parasite drag have been made a minimum (dealt with more fully later), the greatest step forward in aerodynamics will be obtained by removing, or at any rate decreasing to a large extent, the form drag.

The reduction of drag by attention to detail design is well repaid in increased performance of the aircraft, and a section is also devoted to this.

The total drag of the aircraft is obtained from a summation of the various drags of the components, and is usually reduced to a non-dimensional coefficient basis C_D, such that:

Total drag of aircraft $D = C_D \cdot \frac{1}{2}\rho SV^2$, where S is the gross wing area.

Alternatively it may be calculated as :

$$D = C_f \,.\, \tfrac{1}{2}\rho S^1 V^2 \times \text{cleanness factor.}$$

In this case C_f is the coefficient of drag corresponding to laminar or turbulent flow, over a flat plate, depending on Reynolds number, and S^1 is the "wetted" surface of the aircraft.

Cleanness factor should for an ideal aircraft equal 1 but for almost all aircraft it never is less than 2, thus showing the great gap yet to be filled between present-day and the future ideal aircraft.

AEROFOIL DRAG

- PROFILE DRAG (drag of infinite-span wing—aerofoil in two-dimensional flow)
  - SKIN FRICTION DRAG (major part of total drag due to viscous nature of air at $M < 0{\cdot}8$ approx.)
    - LAMINAR boundary layer (low drag)
    - TURBULENT boundary layer (high drag)
  - FORM DRAG (due to component of pressures in direction of drag forces caused by departure from ideal fluid flow due to thickness of boundary layer)
  - COMPRESSIBILITY DRAG (due to influence of shock waves) major part of drag at $M > 0{\cdot}8$ approx.)
    - SHOCK LOSS (small if $M < 1$)
    - FORM DRAG (high after formation of shock wave due to breakaway of airflow)
- INDUCED DRAG (due to vortex system of finite-span wing)

Induced Drag.—In general, the pressure on the top surface of the wing is less than atmospheric and on the bottom surface greater than atmospheric. At the wing tips there is nothing to prevent the air on the undersurface from moving spanwise outwards, round the tip, over to the top surface, then moving spanwise inwards to attempt to equalise these pressures. This causes a rotary motion to the air passing over the aerofoil, as shown in Fig. 3. Thus the finite wing throws off vortices at the trailing edge.

It is seen, too, that due to these trailing vortices the air has a velocity downwards over the span of the wing and upwards outboard of the wing tips. This velocity is termed the induced velocity and is usually denoted by the letter ω. The trailing vortices are clearly strongest close to the wing tips, but the actual distribution across the span depends upon the wing-plan form and wing twist if any; the induced velocities vary correspondingly. Some way downstream the sheet of trailing vortices springing from the wing rolls up into two concentrated vortices separated by a distance rather less than the span. The energy used up in causing these vortices is a dead loss, and shows itself as extra drag, which is termed induced drag. The way in which this drag arises is as follows :

Considering the elliptic plan form, the normal induced velocity can be shown (by calculations in aerofoil theory) to be constant across the span and equal to the value :

$$\omega = \left(\frac{1}{\pi A}\right) . V . C_L \qquad . \quad . \quad . \quad . \quad . \quad (1)$$

where A = Aspect ratio of wing = span ÷ by mean chord.
V = Velocity of air.
C_L = Lift coefficient at which the wing is operating.

It is now seen that the actual angle of incidence of the wing to the airframe, α_0, is given by

$$\alpha_0 = \alpha - \frac{\omega}{V}$$

and the lift becomes tilted backwards through a small angle :

$$= \tan^{-1}\frac{\omega}{V}.$$

The component of the lift resolved backwards parallel to the flight path is :

$$(\tfrac{1}{2}\rho SV^2 C_L)\frac{\omega}{V}.$$

Substituting for $\frac{\omega}{V}$ from (1) this :

$$= \tfrac{1}{2}\rho SV^2 . \frac{C_L^2}{\pi A}$$
$$= \tfrac{1}{2}\rho SV^2 . C_{Di}$$

where C_{Di} is the induced drag coefficient.

$$\text{i.e. } C_{Di} = \frac{C_L^2}{\pi A}.$$

This equation holds for elliptic wings.

For rectangular and straight tapered wings the induced drag is greater than this minimum value, and for these wings the equation is written :

$$C_{Di} = \frac{C_L^2}{\pi A}(1 + \delta).$$

On normal wings of aspect ratio 6 to 7, and with a tip chord to root chord ratio of 0·3 to 0·5, the value of δ for straight tapered plan form is approximately 0·01.

For high-speed aircraft the C_L at normal cruising speed is of the order of 0·2, whence $C_{Di} = \frac{0{\cdot}04}{20} = 0{\cdot}002$. It can be seen, therefore, that the correction, δ, to the quantity $\left(\frac{C_L^2}{\pi A}\right)$ is negligible for all normal types of wing-plan form and, whilst it is zero for the elliptic wing, it becomes questionable whether the structural complications of an elliptic wing will not outweigh the very slight increase in induced drag of the straight tapered wing.

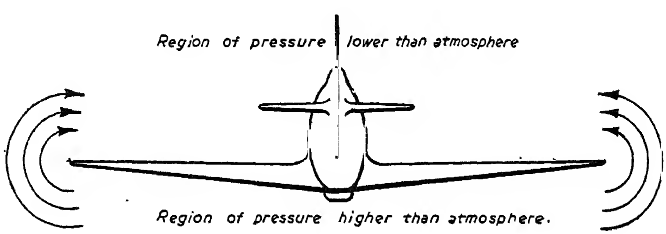


Fig. 1a.—View of aircraft from rear.

Form Drag.—The total profile drag is always the summation of two parts—drag due to friction of the air, tangential to the surface of the body, and drag due to the resolved component of the normal pressure in the direction of flow

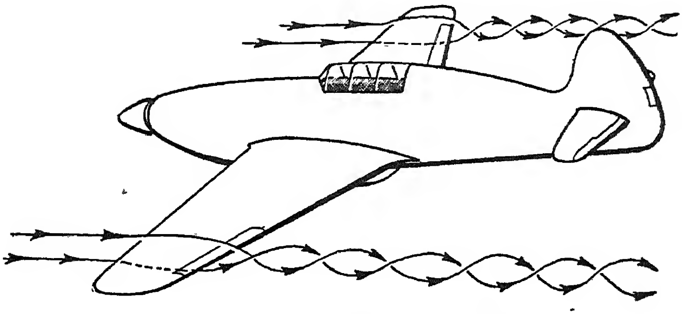


Fig. 2.—Formation of vortices. Airflow over wing.

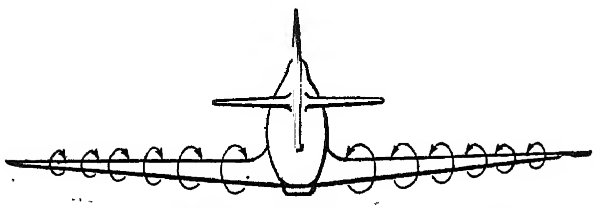


Fig. 3.—View of vortices shed from trailing edge immediately behind aircraft.

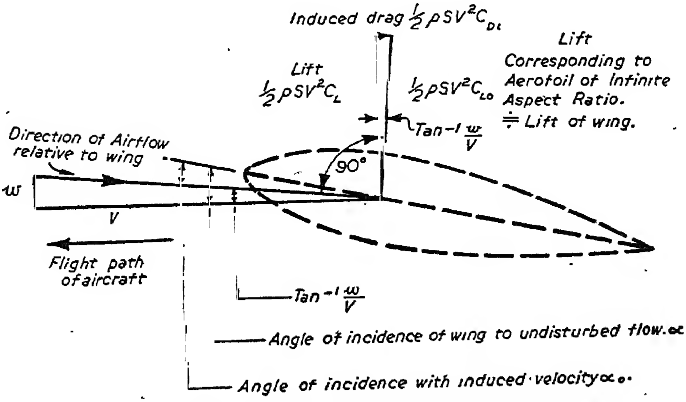


Fig. 4.—Component of lift resolved aft to give value of induced drag.

This latter value is called the form drag of the body, and it may be derived as follows :

Figs. 5 and 6 show typical pressure distributions round streamlined bodies.

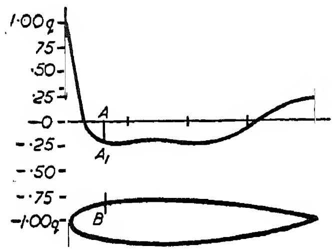


Fig. 5.—Pressure distribution round streamlined body. $\alpha = 0$.

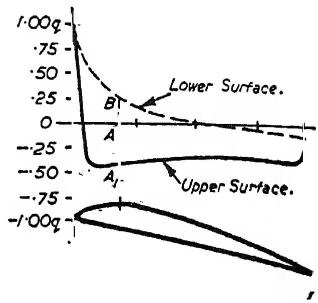


Fig. 6.—Pressure distribution round aerofoil at speed of sound. $\alpha = 12°$.

Two examples have been chosen, Fig. 5 being for a good streamlined shape at moderate airflows, the form drag being very small (3 to 5 per cent. of the total drag), whilst Fig. 6 shows the pressure distribution round an aerofoil at the speed of sound.

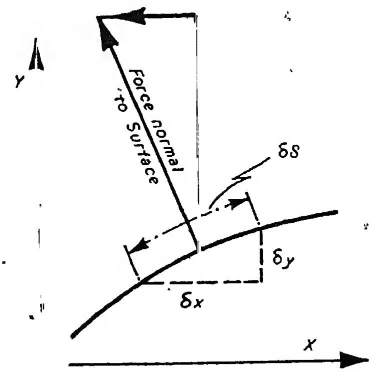


Fig. 7.—Diagram illustrating formulæ for forces acting on streamlined surface.

$$
\begin{aligned}
\text{Force normal to surface of area} &= \text{pressure} \times \text{element} \\
&= p \,.\, \delta S \\
\text{Component along X axis} &= \text{drag force} \\
&= p \,.\, \delta S \sin^{-1} \frac{\delta y}{\delta S} = p \,.\, \delta y \\
&= \text{local pressure} \times \text{projected area of the body in the direction considered.}
\end{aligned}
$$

Over the forward portion of the body the suction causes a force pulling the body forward, whilst over the latter part of the body the suction is tending to

retard the body. Similarly a positive pressure over the forward portion will cause a drag and on the rear portion will cause the body to be forced forwards.

The net resultant of these forces is termed the form drag. It is seen that it will be low for the streamlined body as shown and will be very large for the aerofoil under the conditions illustrated.

Typical values of form drag as a percentage of the total profile drag are :

	Per cent.
Wing at small angles of attack at moderate aircraft speeds	7
,, ,, high ,, ,, ,, ,, ,, ,, ,,	25
Sphere at low Reynolds numbers	95
,, ,, high ,, ,, ...	90

It is seen, too, that the form drag of wings at high speeds, i.e. near the speed of sound, can be very large if steps are not taken to ensure that the airflow remains streamlined.

Calculation of Profile Drag.—Profile drag is sometimes divided into form drag and surface-friction drag, the former being the drag component of the normal pressures as shown above, and for wings, etc., at moderate aircraft speeds being a small fraction of the total.

Surface-friction drag is dependent upon the condition of flow, and in general is very much less when the flow in the boundary layer is laminar than when it is turbulent.

Laminar boundary-layer flow is most readily maintained by a continuously falling pressure. This is the state of affairs at the nose of an aerofoil, and the so-called low-drag or laminar-flow aerofoils extend this falling pressure as far back as possible along the chord at a chosen lift coefficient, called the design-lift coefficient. This leads to sections for which the maximum thickness is far back.

Knowledge of the pressure distribution is desirable, since the transition from laminar to turbulent flow takes place slightly downstream of minimum pressure

DRAG COEFFICIENT C_D OF STREAMLINED SOLIDS OF REVOLUTION

Total Drag $= C_D \times \frac{1}{2}\rho V^2 S$, where S is the surface area of the body.
d = Max. dia. of body.
l = Length of body.

Transition point	*dia./length* \ *Reynolds No.*	4×10^6	10×10^6	20×10^6	40×10^6
At nose . .	0·30	0·0048	0·00405	0·00360	0·00320
	0·25	0·00445	0·00377	0·00335	0·00302
	0·20	0·0042	0·00356	0·00317	0·00285
	0·15	0·0040	0·00342	0·00303	0·00270
	0·10	0·0038	0·00325	0·00289	0·00258
	0	0·0036	0·00306	0·00272	0 00242
At 0·12 . .	0·30	0·00455	0·00382	0·00340	0·00303
	0·25	0·0042	0·00355	0·00317	0·00284
	0·20	0·0039	0·00335	0·00297	0·00265
	0·15	0·00375	0·00315	0·00280	0·00248
	0·10	0·00355	0·00300	0·00265	0·00236
	0	0·0033	0·00282	0·00250	0·00220
At 0·22 . .	0·30	0·00425	0·00356	0·00316	0·00282
	0·25	0·00395	0·00330	0·00292	0·00260
	0·20	0·00375	0·00305	0·00270	0·00243
	0·15	0·0035	0·00290	0·00255	0·00227
	0·10	0·0033	0·00276	0·00240	0·00216
	0	0·0031	0·00258	0·00226	0·00204

PROFILE DRAG COEFFICIENTS, C_D OF WINGS

Total profile drag = $C_D \times \frac{1}{2}\rho S^1 V^2$

t = Thickness of wing. c = Chord.

	Max. thickness at 0·3 chord		*Max. thickness at 0·5 chord*	
$\frac{t}{c}$	R = 4 × 10⁶	40 × 10⁶	4 × 10⁶	40 × 10⁶
Transition at leading edge :				
0·25	0 0141	0·0102	—	—
0·20	0·0122	0·0085	0·0119	0·0083
0·15	0·0106	0·0073	0·0107	0·0073
0·10	0·0092	0·0063	0·0096	0·0064
0·05	0·0080	0·0055	0·0083	0·0056
0	0·0069	0·0048	0·0071	0·00485
Transition at 0·1c behind leading edge :				
0·25	0·0130	0·0090	—	—
0·20	0·0112	0·0077	0·0112	0·0077
0·15	0·0096	0·0065	0·0102	0·0067
0·10	0·0085	0·0057	0·0089	0·0059
0·05	0·0075	0·0050	0·0078	0·0052
0	0·0067	0·0044	0·0068	0·0044
Transition at 0·2c :				
0·25	0·0115	0·0077	—	—
0·20	0·0100	0·0066	0·0103	0·0070
0·15	0·0086	0·00575	0·0092	0·0062
0·10	0·0076	0·0051	0·0082	0·0054
0·05	0·0068	0·0045	0·0071	0·0047
0	0·0063	0·0041	0·0062	0·0041
Transition at 0·4c :				
0·25	0·0079	0·0049	—	—
0·20	0·0071	0·0044	0·0084	0·0054
0·15	0·0064	0·00405	0·0074	0·0048
0·10	0·0058	0·0037	0·0067	0·0042
0·05	0·0054	0·0034	0·0059	0·0037
0	0·0050	0·0032	0·0051	0·0033
Transition at 0·6c :				
0·25			—	—
0·20			0·0060	0·00365
0·15			0·0055	0·0034
0·10			0·0050	0·0031
0·05			0·0045	0·0028
0			0·0041	0·0025

(wing smooth and free from waviness). Failing a knowledge of pressure distribution, the assumption of transition at the position of maximum thickness will be conservative for low-drag wings at the design-lift coefficient. These low-drag properties will in many cases be maintained over a lift coefficient of about 0·3 on either side of the design-lift coefficient. Outside this range the drag of all aerofoils should be calculated on the assumption of mean transition points at, say, 0·1 or 0·2 chord from the leading edge.

For streamline bodies transition will generally occur at the nose.

Interference Drag.—The flow of air past a streamlined body is influenced for some considerable distance above and below the body. If another streamlined body is placed in the vicinity of the first, then the flow pattern over the first one is altered from its previous value. Similarly the first streamlined body influences the flow over the other. This knowledge is made use of for improving the properties of aerofoils near the stall by fitting slots or auxiliary aerofoils close to and just ahead of the top surface of the wing. However, in most cases the proximity of two streamlined bodies causes an additional drag so that the total drag of the combination is greater than the sum of the separate drags of each when tested alone. This occurs at the junction of the wing and fuselage, tailplanes and fin, etc., and where streamlined tanks or bodies are suspended beneath wings.

The interference drag can be reduced by suitable design. For wing-fuselage combinations the interference drag may vary from zero to as much as 60 per cent. of the combined total of the separate wing and fuselage drags.

High- or mid-wing combinations give the minimum, and low-wing monoplanes (particularly when the wing is tangential to the bottom surface of the fuselage) give worst interference. In the case of low-wing monoplanes the drag can be reduced considerably by suitably designed wing fillets. With a good-design fillet the interference drag can be reduced to about 10 per cent. of the sum of the separate wing and fuselage values, and this value can be used as a rough-and-ready rule when assessing total aircraft drag.

Parasite Drag.—This is the term given to the drag of excrescences such as wireless aerials, blisters, mass balance weights, etc., fitted to the aircraft and exposed to the airstream.

For high-speed aircraft the parasite drag may be as much as 30 per cent. of the total drag of the aircraft at its maximum speed and every effort should be made to avoid it. This in general is what determines whether an aircraft is "clean" or "dirty," a clean one having the minimum of external excrescences.

Aerofoil Drag at High Speeds.—When the air velocity over the aerofoil reaches the speed of sound a shock wave is formed and, depending on the shape of the aerofoil section aft of the shock wave, the flow may or may not break away—if the latter, then the aerofoil will suffer from very high form drag (see Form Drag). The critical Mach number at which this occurs is a direct relation to the pressure difference on the aerofoil. A low-pressure difference will postpone this event, but for laminar flow it is a requirement that the pressure gradient is continuously positive and of at least a certain value. It is seen, therefore, that the aerofoil design is a compromise, and should be such as to give the minimum values of the particular forms of drag at the particular operating conditions of the aircraft.

Reduction of Aircraft Drag.—On high-speed aircraft with aerodynamically smooth wings, fuselage, and empennage, the parasite drag may be as much as 40 per cent. of the total aircraft drag at 450 m.p.h., and even more than this at higher speeds. Expressed in the practical form that with an engine developing 2,000 h.p., 800 of these may be used up in dragging through the air excrescences such as wireless masts, exhaust stacks, gun-port fairings, mass balance-weights on controls, fairings of flap-operating mechanisms, etc., it can be seen why the importance of parasite-drag reduction cannot be over-emphasised.

The ideal, of course, is to have no excrescences at all, but where it does become necessary (in order to comply with, say, a specific purpose for which an aircraft may be built), the following information should reduce the parasite drag to a practical minimum.

Excrescences on Aerofoils: When such excrescences cannot be avoided they should be positioned more that one-tenth of the chord aft of the maximum

thickness of the wing, and preferably on the bottom surface. Particular care should be taken to keep the nose of the aerofoil absolutely clean. When an excrescence is situated forward of the position given above, the drag of the wing itself is considerably increased over a section much wider than the excrescence itself.

Narrow Passages, Sudden Expansions, etc.: It is highly important that no excrescences should be allowed in the vicinity of an area in which the airflow is constricted.

Whenever there is a tendency for the airflow to be forced through a narrow passage (as in the case of the wing-to-fuselage junction on low-wing aircraft) careful attention should be paid to the design of the fillet. This also applies where sudden expansions of the airstream are likely to occur.

Skin Joints, Bolts, Hinges for Removable Doors, etc.: Bolts, hinges, etc., should on no account be allowed to project into the airstream. Hinges for access doors should, if possible, be positioned in the direction of flow rather than across it. On a curved surface such as the leading edge of an aerofoil, this can be avoided by using "set back" hinges.

All skin joints must be made flush, as minimum drag can be obtained only when the surface does not deviate more than two-thousandths of an inch from the designed contour.

Vent Pipes, Breathers, etc.: The ends of vent pipes and engine breathers, etc., should be finished flush and not allowed to project into the airstream. A collar, which will prevent leaks into the inside of the fuselage, should be fitted, provision being made for variations due to tolerances or ill-fitting panels, etc.

The best position for such vent pipes is in the vicinity of the radiator duct outlet, and all vent pipes should be grouped together at their exit.

Draught Sealing, Fuselage Holes, etc.: A large decrease in the total drag can be obtained if all air leaks are properly sealed. Care should be taken therefore to seal off all holes in the fuselage and cowling, and, when this cannot be done directly (as in the case of the tail wheel and spinner gap), to isolate such openings from the remainder of the aircraft by a diaphragm.

Compressibility.—Compressibilitye ffects only begin to outweigh the ordinary aerodynamic effects at speeds above, say, 400 m.p.h., although for airscrew design compressibility makes itself felt at much lower aircraft speeds.

Throughout the subject constant reference is made to the Mach number by which one can visualise the effects of compressibility.

The Mach number, $\frac{V}{a}$, is purely the ratio of the speed of the aircraft V to the local speed of sound a. The local speed of sound at various heights in the standard atmosphere is given in Table I, where it is seen that the speed drops some 13·3 per cent. at 35,000 ft. compared with its value at sea-level.

The lift and drag of an aircraft depend among other things on the density of the atmosphere and the square of the speed V of the aircraft. Considering an aircraft at ground level and at 35,000 ft., it is seen that the value of lift L must remain the same for steady flight, and since ρ decreases by 69 per cent. the speed to maintain lift must increase by some 45 per cent. So that the aircraft has its Mach number increased by $\frac{1 \cdot 45}{0 \cdot 867} = 1 \cdot 67$, i.e. by roughly 67 per cent. This analysis does not in fact hold good, but it is given here to show qualitatively the importance of Mach number with height.

The chief effects of increase of Mach number on the aerodynamic characteristics of the aircraft are as follows:

(1) Very large increase in drag as M approaches 1 due to formation of shock waves and separation.

(2) Increase in lift until the CRITICAL Mach number is reached, after which high-speed stall takes place and the lift drops.

(3) Increase in pitching moment.

The very large increase in drag is due to the separation of air from the body, leaving a completely turbulent wake immediately aft of the position or positions on the body of the shock waves. The actual drag due to energy dissipation in

the wave is comparatively small, and the drag due to increase in profile drag is believed negligible.

Up to the actual shock stall the lift increases in the ratio

$$\frac{\left(\frac{dC_L}{d\alpha}\right)_C \text{ at Mach N°M}}{\left(\frac{dC_L}{d\alpha}\right)_i \text{ in incompressible flow}} = \frac{1 + \frac{\frac{dC_L}{d\alpha}}{\pi A}}{\beta + \frac{\frac{dC_L}{d\alpha}}{\pi A}}$$

where $\beta = \frac{1}{\sqrt{1 - M^2}}$ and A = Aspect ratio

$\left(\frac{dC_L}{d\alpha}\right)_C$ = slope of lift curve in compressible flow at Mach No. M.

$\left(\frac{dC_L}{d\alpha}\right)_i$ = slope of lift curve in incompressible flow.

The effect on pitching moment C_{MO} is given by the formula :

$$(C_{MO})_C = (C_{MO})_i \times H$$

where $H = \frac{1}{\sqrt{1 - M^2}} + 5{\cdot}9\,\frac{t}{c}\,.\,M^5$

C_{MO} = pitching moment coefficient at zero lift.

$\frac{t}{c}$ = thickness chord ratio of the aerofoil.

For values of pitching moment coefficient, C_M, about the quarter-chord point of an aerofoil at a given incidence, the following approximate formula may be used :

$$(C_M)_C = (C_M)_i\,.\,H + 1{\cdot}9\,\frac{t}{c}\,(C_L)_i\,M^5$$

where the symbols have the same meaning as in the equation above.

Critical Mach Numbers.—The critical Mach number of a body is the Mach number at which the velocity somewhere on the body first reaches the local speed of sound. It may be determined experimentally from pressure distribution measurements, or be calculated. Table on page 1266 gives the values of critical Mach number against maximum suction coefficient and maximum local velocity on a body determined for incompressible flow.

At a Mach number a little in excess of these critical values, shock waves develop from the body, and with still further increase in Mach number the shock waves cause flow breakaway, and rapid changes in drag, lift, and pitching moment follow in consequence. Some rise in drag coefficient is generally first in evidence after the critical Mach number is passed, due to the loss of energy across the growing shock wave ; this energy loss is a factor whether the flow has separated or not. The Mach number, above which the lift coefficient falls and the pitching-moment characteristics show fairly rapid changes, can be identified as that at which flow breakaway begins. This Mach number is, therefore, generally higher than that at which the drag coefficient begins to rise.

Hence the critical Mach number is a warning of impending rapid and generally adverse changes in the aerodynamic forces and moments.

For high-speed flight it is therefore essential to keep the maximum suction pressures as low as possible and high-speed aerofoils are designed with this in view, usually by designing the wing section to have "roof top"-type pressure distribution over the aerofoil, and by keeping the thickness-chord ratio as small as is practical.

Of particular importance is the avoidance of peak suction pressures at positions of interference of wings and fuselages or engine nacelles, and these peak pressures should be determined (and avoided as much as possible) in the initial stages of design by wind-tunnel tests on models.

CRITICAL MACH NUMBER FROM LOW-SPEED PRESSURE DISTRIBUTION AND FROM LOW-SPEED VELOCITY DISTRIBUTION

Max. Suction Coeff. C_p	*Max. Local Vel. Ratio* $\frac{V_1}{V_0}$	*Critical Mach No.* $M_c = \frac{V_c}{a}$
0	1·00	1·00
0·2	1·09	0·82
0·4	1·19	0·73
0·6	1·27	0·67
0·8	1·35	0·62
1·0	1·41	0·585
1·2	1·49	0·55
1·4	1·37	0·52
1·6	1·62	0·50
1·8	1·68	0·48
2·0	1·75	0·46
2·2	1·80	0·445
2·4	1·86	0·43
2·6	1·90	0·42
2·8	1·94	0·41
3·0	2·0	0·395

:locity relative to undisturbed air at which the local speed of sound is ached somewhere on the body (ft./sec.).

locity relative to undisturbed air at which pressure distribution is not :iously dependent on compressibility (ft./sec.).

a — speed of sound in undisturbed air (ft./sec.).

V_1 = Maximum local velocity on the body when the velocity of the undisturbed stream is V_0 (ft./sec.).

p_0 = Pressure in undisturbed stream at velocity V_0 (lb./sq. ft.).

p = Minimum pressure on the body at velocity V_0 (lb./sq. ft.).

ρ = Density of undisturbed air (slug/sq. ft.).

C_p = Maximum suction coefficient $\left\{\frac{(p_0 - p)}{\frac{1}{2}\rho V_0^2}\right\}$.

PERFORMANCE ESTIMATION OF AIRCRAFT BY APPROXIMATE METHODS

Profile Drag and Drag other than Induced.—Whilst the previous work gives the detailed methods of assessing the drag of a particular design, it is useful to have a general idea of the overall drag of various types of aircraft. The table below shows the more usual ranges of the drag of different types, the range being quoted for aerodynamically "clean" and "dirty" aircraft in each particular type.

A "clean" aircraft is one having fine lines and very few excrescences, i.e. small thickness-chord ratio of the wings, no blisters for equipment to spoil the lines, no wireless aerial loops or Christmas-tree shapes, smooth streamlined cockpit, ample wing fillets, and good radiator-duct arrangements. A "dirty" aircraft is one having some of the above-mentioned excrescences.

Values of drag taken from the table will be found quite as reliable for most purposes as the more accurate method based on a calculation of the wetted area, since on present-day aircraft bad aerodynamic design accounts for the major part of the drag losses.

Type	C_{D_0}
Fighters and fighter bombers . . .	0·018 to 0·025
Medium bombers	0·025 to 0·031
Heavy bombers, flying-boats, and transport aircraft	0·030 to 0·042

Then the drag in pounds at 100 ft./sec. at ground level without the induced drag is given by:

$$D_0 \text{ lb.} = C_{D_0} \times 11{\cdot}9S$$

where S is gross wing area in square feet.

Estimation of True Air Speed.—The speed for any particular power can be calculated from the formula:

$$\eta \text{ BHP} + \text{THP}_E = D_{100}V^3\sigma \times 5{\cdot}73 \times 10^{-7}$$

where η = Airscrew efficiency (see below).
BHP = Brake horse-power of the engine at the altitude concerned.
THP_E = Exhaust thrust horse-power.
V = True air speed (m.p.h.).
σ = Relative air density.
D_{100} = Total drag at 100 ft./sec. at ground level
$= D_0 + D_i$ where
D_i = Induced drag in pounds at 100 ft./sec. at ground level
$= \left(\frac{W}{V^2\sigma b}\right)^2 \times 5{\cdot}75 \times 10^5.$
W = Weight of aircraft (lb.).
b = Span in feet.

In the case of high-speed aircraft the induced drag at top speed is small and can often be neglected.

The airscrew efficiency can be taken as 0·82 below 380 m.p.h. Above this speed the efficiency tends to fall off due to the effect of high airscrew-tip speeds. The amount of this falling off will vary with the particular tip speeds concerned, and it is difficult to give a general rule. The table below gives suggested values which can be used as a rough guide.

Speed, m.p.h. .	*Below* 380	400	425	450	475
Airscrew, η per cent.	82	80	78	74	68

These values assume that the airscrew has been designed for the top-speed conditions.

Engine powers are generally quoted at static altitude conditions. The forward speed of the aircraft, however, increases the pressure in the air intake, so that the maximum level speed of the aircraft is obtained at a height somewhat above the engine height quoted. At 400 m.p.h. this increase is of the order of 4,000 ft.

Exhaust Thrust.—At low speeds the exhaust thrust is small, but at high speeds exhaust thrust is of considerable importance. Typical values of exhaust thrust as a percentage of b.h.p. are:

True Air Speed:	250	300	350	400	450
	Per Cent.	*Per Cent.*	*Per Cent.*	*Per Cent.*	*Per Cent.*
At 20,000 ft. .	6·0	8·5	11·5	14·5	17·5
„ 5,000 ft. .	4·5	7·0	10·0	13·0	16·0

Range.—A useful formula for range estimation is that the range is equal to 80 to 90 miles per percentage of all-up weight of fuel available for cruise depending on the "cleanness" of the aircraft. For example, if the weight of fuel available for cruise is 10 per cent. of the all-up weight of the aircraft, the range is 900 miles for a "clean" aircraft and 800 miles for a "dirty" one.

The above formula takes into account the fact that the theoretical optimum cruise speed conditions cannot be reached, as it is below the minimum comfortable cruising speed of the aircraft. The minimum comfortable cruise speed can be defined as that speed at which the pilot still has sufficient rate of climb available to recover small losses in altitude, such as may occur in bumps, etc.

MATERIALS FOR AIRCRAFT CONSTRUCTION

Wood.—The chief merits of wood for aircraft construction are a high ratio of strength to weight; an inherent lightness in weight which, for a given depth of member, permits considerable width to afford lateral stability against buckling; the ease with which it can be manufactured and assembled and, for the same reason, the highly skilled labour on special equipment; its relative cheapness; its adaptability to production in small plants; and the readiness with which it may be glued and spliced. In addition, the present knowledge of wood permits selection so as to obtain both the uniformity necessary for quantity production and the properties that are best for the work in hand.

On the other hand, the principal factors tending to restrict the use of wood are a not unlimited supply of the most desirable species; a hygroscopicity that results in shrinking and swelling and changes in strength; and a wide difference in properties with different directions of the grain. For high-speed aircraft, the torsional stiffness of the aircraft structure is a major consideration, and difficulty in providing a satisfactory margin of stiffness for safety is met if attempts are made to use wood for the structure without a metal covering.

The table presents strength data on various woods for use in aircraft design. The values are based on a moisture content of 15 per cent. and a duration of stress of three seconds. The minimum acceptable and the average specific gravities are included, as well as the weight per cubic foot of material at 15 per cent. moisture content. These design values have been adopted by the American aircraft industry, and may be used with confidence. The stress values listed apply only to material that meets the minimum requirements for specific gravity and the limitation of defects.

The table was prepared from the results of a series of tests carried out on standard specimens 2×2 in. in cross section. Attention is drawn to the value of the form factor which must be applied to the results, should other types of beam or closed-section box form of construction be envisaged. This form factor may be as low as 0·5 for some extreme sections in I and box beams, whereas it is greater than unity in some cases.

Properties of wood needed in design not quoted in the above table:

(1) *Tension:* Values quoted for the modulus of rupture given in the table may safely be used when tension-parallel-to-the-grain figures are necessary.

(2) *Torsion:* Values one-third greater than the shearing-strength values quoted in the table may be used for maximum permissible torsional stress. The elastic-limit torsional stress may be assumed two-thirds of the maximum permissible torsional stress.

(3) *Modulus of Rigidity:* For spruce, the value may be taken as the modulus of elasticity along the grain divided by 15·5. For other woods a conservative value is their modulus of elasticity divided by 17.

A considerable amount of the above information was extracted from N.A.C.A. Report No. 354, and for further details reference to the original report is suggested.

The modern trend is to use "sandwich" construction, i.e. thin surfaces of metal between which is a sandwich of wood. Outstanding improvements to aircraft structures and aerodynamic finish will be obtained with this type of construction which, at the moment, is not widely used, pending the production of a *reliable* method of attaching the wood to the metal.

Plastics as used in aircraft are dealt with in the Plastics section.

Metal.—Metals used in aircraft construction may be classified in two general groups: (1) ferrous—those metals composed largely of iron; and (2) non-ferrous—those metals constitutionally independent of iron.

These two groups may again be subdivided into several groups, of which steel is the only ferrous material used structurally in aircraft, whilst of the non-ferrous groups aluminium alloys and magnesium alloys form the major structural groups. Apart from these, there are a few specialised metals indispensable in some parts of the aircraft for bearings, pipes, cables, and electrical services.

Steel may be classified into three main groups :

(1) Carbon steels.

(2) Alloy steels.

(3) Stainless (non-corrodible) steels.

These groups may again be subdivided into various classes as follows :

Carbon steels : Are of three types : mild, medium-carbon, and high-carbon steel, according to the carbon content.

Alloy steels : Are of two types : medium high-tensile and high-tensile steels, according to their composition and heat treatment.

Stainless steels : Are of three types :

(*a*) Simple or standard 12 per cent. chromium non-corrodible steel contains nickel up to 1 per cent. and chromium not less than 12 per cent. It is magnetic and may be hardened by heat treatment. This class of steel is referred to in D.T.D. specifications as non-corrodible steel.

(*b*) "Two-score" non-corrodible steel contains from 1 to 3 per cent. nickel and 16 to 20 per cent. chromium. It is magnetic and may be hardened by heat treatment. This class of steel is referred to in D.T.D. specifications as high-chromium non-corrodible steel.

(*c*) Austenitic non-corrodible steel (known as Staybrite or 18/8) contains not less than 6 per cent. nickel and not less than 12 per cent. chromium. For practical purposes it is non-magnetic and can be hardened only by cold working. This class of steel is referred to in D.T.D. specifications as chromium-nickel non-corrodible steel.

The simple or standard 12 per cent. chromium non-corrodible steels should not be used in direct contact with non-corrodible steel of the Austenitic composition, although either may be used in contact with non-corrodible steel of the "Two-score" type.

Refer to the metallurgical section for full information concerning metals.

ALUMINIUM ALLOYS—CLASSIFICATION AND HEAT TREATMENT

Types of Aluminium Alloys.—The wrought aluminium alloys used in aircraft construction can be classified into two types—see Table I.

(*a*) Those alloys in which the strength is developed by cold working or strain hardening.

(*b*) Those alloys in which the strength is developed by suitable heat treatment.

As a general rule it will be found that the chief alloy with aluminium to produce (*a*) is magnesium and the chief alloy in (*b*) is copper. In fact, if an aluminium alloy has more than $\frac{1}{2}$ per cent. (0·05) by weight of copper present, it will respond to heat treatment. This is because the copper combines with aluminium to form a new constituent $CuAl_2$ held in solution in the aluminium, the amount held in solution being dependent on the temperature.

Heat Treatment.—The heat treatment of aluminium alloys consists of three distinct phases :

(1) Heating the alloy to ensure the $CuAl_2$ is dissolved in the crystals of aluminium, i.e. to ensure the $CuAl_2$ is in solution.

(2) Cooling the alloy rapidly from this temperature, i.e. quenching to ensure the $CuAl_2$ remains dissolved in the crystals.

(3) Ageing, which may either be done spontaneously or as a result of low-temperature reheating. In this process the $CuAl_2$ is precipitated out of solution in a finely dispersed or scattered form, the particles then act as keys and interfere with slippage along the crystallographic slip planes, thus increasing the strength of the alloy.

STRENGTH VALUES OF VARIOUS WOODS, BASED ON 15 PER CENT. MOISTURE CONTENT, FOR USE IN AIRCRAFT DESIGN

Species of Wood ; Common and Botanical Names	Specific Gravity based on Volume and Weight when Oven Dry		Weight at 15 per cent. Moisture Content	Shrinkage from Green to Oven-dry Condition based on Dimensions when Green		Static Bending				Compression Parallel to Grain		Compression Perpendicular to Grain[4]	Shearing Strength Parallel to Grain[5]	Hardness Side ; Load required to embed ·444-in. Ball to One-half its Diameter
	Average	Minimum Permitted		Radial	Tangential	Fibre Stress at Elastic Limit[1]	Modulus of Rupture[1]	Modulus of Elasticity[2]	Work to Maximum Load	Fibre Stress at Elastic Limit[1–3]	Maximum Crushing Strength[1]			
			Lb. per cu. ft.	Per cent.	Per cent.	Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	Inch lb. per cu. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb. per sq. in.	Lb.
HARDWOODS (BROAD-LEAVED SPECIES)														
Ash, black (*Fraxinus nigra*)	0·53	0·48	35	5·0	7·8	6,400	11,900	1,340	14·3	4,050	5,400	1,260	1,050	760
Ash, commercial white (*Fraxinus spp.*)[6]	0·62	0·56	41	4·3	6·9	8,900	14,800	1,460	14·2	5,250	7,000	2,250	1,380	1,180
Basswood (*Tilia glabra*)	0·40	0·36	26	6·6	9·3	5,600	8,600	1,250	6·6	3,370	4,500	620	720	370
Beech (*Fagus grandifolia*)	0·66	0·60	44	4·8	10·6	8,200	14,200	1,440	13·5	4,880	6,500	1,670	1,300	1,060
Birch (*Betula spp.*)[7]	0·68	0·58	44	7·0	8·5	9,500	15,500	1,780	18·2	5,480	7,300	1,590	1,300	1,100
Cherry, black (*Prunus serotina*)	0·53	0·48	36	3·7	7·1	8,500	12,500	1,330	11·7	5,100	6,800	1,170	1,180	900
Cottonwood (*Populus deltoides*)	0·43	0·39	29	3·9	9·2	5,600	8,600	1,190	7·4	3,520	4,700	650	660	410
Elm, rock (*Ulmus racemosa*)	0·66	0·60	45	4·8	8·1	7,900	15,000	1,340	19·3	5,180	6,900	2,090	1,360	1,230
Gum, red (*Liquidambar styraciflua*)	0·53	0·48	34	5·2	9·9	7,500	11,600	1,290	10·9	4,050	5,400	1,190	1,100	650
Hickory (true hickories) (*Hicoria spp.*)[8]	0·79	0·71	51	—	—	10,600	19,300	1,860	27·5	6,520	8,700	3,100	1,440	—
Mahogany, "African" (*Khaya spp.*)	0·47	0·42	32	4·8	5·5	7,900	10,800	1,280	8·0	4,280	5,700	1,400	980	720
Mahogany, true (*Swietenia spp.*)[9]	0·51	0·46	34	3·4	4·7	8,800	11,600	1,260	7·3	4,880	6,500	1,760	860	790
Maple, sugar (*Acer saccharum*)	0·67	0·60	44	4·8	9·2	9,500	15,000	1,600	13·7	5,620	7,500	2,170	1,520	1,270
Oak, commercial white and red (*Quercus spp.*)[10]	0·69	0·62	45	4·6	9·0	7,800	13,800	1,490	13·6	4,950	6,600	1,870	1,300	1,240
Poplar, yellow (*Liriodendron tulipifera*)	0·43	0·38	28	4·0	7·1	6,000	9,100	1,300	6·5	3,750	5,000	810	800	420
Walnut, black (*Juglans nigra*)	0·56	0·52	39	5·2	7·1	10,200	15,100	1,490	11·4	5,700	7,600	1,730	1,000	900
SOFTWOODS (CONIFERS)														
Cedar, incense (*Libocedrus decurrens*)	0·36	0·32	25	3·3	5·7	6,000	8,700	1,020	5·6	4,320	5,400	900	650	450
Cedar, northern white (*Thuja occidentalis*)	0·32	0·29	22	2·1	4·9	4,700	6,600	700	4·9	3,040	3,800	560	610	300

Cedar, Port Orford (*Chamæ cyparis lawsoniana*)	0·44	0·40	30	4·6	6·9	7,400	11,000	1,520	8·7	4,880	6,100	1,030	760	520
Cedar, western red (*Thuja plicata*)	0·34	0·31	23	2·5	5·1	5,100	7,800	1,030	5·8	4,000	5,000	800	630	320
Cypress, southern (*Taxodium distichum*)	0·48	0·43	32	3·9	6·1	7,100	10,500	1,270	7·7	4,960	6,200	1,230	720	480
Douglas fir (*Pseudotsuga taxifolia*)	0·51	0·45	34	5·0	7·8	8,000	11,500	1,700	8·1	5,600	7,000	1,300	810	620
Pine, northern white (*Pinus strobus*)	0·38	0·34	26	2·2	6·0	5,900	8,700	1,140	6·3	3,840	4,800	780	640	380
Pine, Norway (*Pinus resinosa*)	0·51	0·46	34	4·6	7·2	8,500	11,900	1,560	8·9	5,280	6,600	1,080	870	520
Pine, sugar (*Pinus lambertiana*)	0·38	0·34	26	2·9	5·6	5,600	8,000	1,040	5·4	3,680	4,600	810	730	370
Pine, western white (*Pinus monticola*)	0·42	0·38	27	4·1	7·4	6,000	9,300	1,310	7·9	4,240	5,300	750	640	360
Spruce (*Picea spp.*)[11]	0·40	0·36	27	4·1	7·4	6,200	9,400	1,300	7·8	4,000	5,000	840	750	440

[1] The average values for fibre stress at elastic limit and modulus of rupture in static bending, and fibre stress at elastic limit and maximum crushing strength in compression parallel to grain, have been multiplied by two factors to obtain values for use in design. A statement of these factors and of the reasons for their use follow: It was thought best, in fixing upon strength values for use in design, to allow for the variability of wood and the fact that a greater number of values are below the average than above it, and the most probable value (as represented by the mode of the frequency curve) was accordingly decided upon as the basis for design figures. From a study of the ratios of most probable to average values for three species (Sitka spruce, Douglas fir, and white ash) 0·94 was adopted as the best value of this ratio for general application to the properties in question. The stress that wooden members can carry depends on its duration. A factor of 1·17 has been applied to test results to get values of the stress that can be sustained for a period of three seconds, it being assumed that the maximum load will not be maintained for a longer period.

[2] The values given are 92 per cent. of the average apparent modulus of elasticity (E_e) as obtained by substituting results from tests of 2×2-in. beams on a 28-in. span with load at the centre in the formula $E_e = Pl^3/48\Delta I$. The use of these values of E_e in the usual formulæ will give the deflection of beams of ordinary length with but small error. For exactness in the computation of deflections of I and box beams, particularly for short spans, the formula that takes into account shear deformations (see National Advisory Committee for Aeronautics Report No. 180, *Deflection of Beams with Special Reference to Shear Deformations*) should be used. This formula involves E_t, the true modulus of elasticity in bending, and F, the modulus of rigidity in shear. Values of E_t may be obtained by adding 10 per cent. to the values of E_e as given in the table. If the I or box beam has the grain of the web parallel to the axis of the beam, or parallel and perpendicular thereto, as in some plywood webs, the value of F may be taken as $E_t/16$ or $E_e/14{\cdot}5$. If the web is of plywood with the grain at 45 degrees to the axis of the beam, F may be taken as $E_t/5$ or $E_e/4{\cdot}5$.

[3] Design values for fibre stress at elastic limit in compression parallel to grain were obtained by multiplying the values of maximum crushing strength as given in the next column by factors as follows: 0·75 for hardwoods; 0·80 for conifers. Values as given are to the nearest 10 lb.

[4] Wood does not exhibit a definite ultimate strength in compression perpendicular to grain, particularly when the load is applied over only a part of the surface, as it is at fittings. Beyond the elastic limit the load continues to increase slowly until the deformation and crushing become so severe as to seriously damage the wood in other properties. Figures in this column were obtained by applying a duration-of-stress factor of 1·17 (see note 1) to the average elastic-limit stress and then adding $33\frac{1}{3}$ per cent. to get design values comparable to those for bending, compression parallel to grain, and shear as listed in the table.

[5] Values in this column are for use in computing resistance of beams to longitudinal shear. They are obtained by multiplying average values by 0·75. This factor is used because of the variability in strength and in order that failure by shear may be less probable than failure from other causes. Furthermore, tests have shown that because of the favourable influence upon the distribution of stresses resulting from limiting shearing deformations, the maximum strength-weight ratio and minimum variability in strength are attained when I and box beams are so proportioned that the ultimate shearing strength is not developed and failure by shear does not occur.

[6] Includes white ash (*F. americana*), green ash (*F. pennsylvanica lanceolata*), and blue ash (*F. quadrangulata*).

[7] Includes sweet birch (*B. lenta*) and yellow birch (*B. lutea*).

[8] Includes bigleaf shagbark hickory (*H. laciniosa*), mockernut hickory (*H. alba*), pignut hickory (*H. glabra*), and shagbark hickory (*H. ovata*).

[9] Includes material from Central America and Cuba.

[10] Includes white oak (*Q. alba*), bur oak (*Q. macrocarpa*), swamp chestnut oak (*Q. prinus*), post oak (*Q. stellata*), red oak (*Q. borealis*), southern red oak (*Q. rubra*), laurel oak (*Q. laurifolia*), water oak (*Q. nigra*), swamp red oak (*Q. pagodæfolia*), willow oak (*Q. phellos*), and yellow oak (*Q. velutina*).

[11] Includes red spruce (*P. rubra*), white spruce (*P. glauca*), and Sitka spruce (*P. sitchensis*).

The heat treatments (1) and (2) are therefore called "Solution Treatment," whilst the phase (3) is called the "Precipitation Treatment." Alternatively (3) is known as "Age Hardening," i.e. it will occur in any event if left at room-temperature for a sufficiently long period. If the period is too long, the process is hastened by warming up the material, in which case it is called "Artificial Ageing." A useful corollary to this is that if the alloy is kept at a low temperature, i.e. below 0° C., the automatic ageing process will be retarded so much that the effects of solution treatment can be retained for a long period. This is extremely useful for maintaining light-alloy rivets in the best condition for being used.

The above statements, although by themselves not the complete explanation, form a useful guide to the internal process of heat treatment of the alloy. Other metals besides copper form solutions in aluminium: magnesium silicide (Mg_2Si), for instance, exhibits a similar effect to that of copper.

The solution heat treatment for the more common alloys is shown in Table II, and precipitation treatment for those alloys which do not strengthen up quick enough by natural means is given in Table III.

The temperature used in practice in the solution treatment must be somewhat below the theoretical maximum due to slight variations in composition of the alloy and to lack of uniformity in the temperature distribution within the furnace. The figures specified for an alloy must therefore be rigorously maintained, as slight overheating results in cracks when a bend test is applied, whilst severe overheating (burning) may be revealed as blisters on the surface of the metal. The parts are then fit only for scrap—this *cannot* be rectified by long reheating at the correct temperature. Temperatures that are too low result in low mechanical properties which, at worst, can be put right by reheat treatment at the correct temperature. Material other than the aluminium-coated alloys may be reheat treated any number of times provided that the treatment is carefully performed and in air furnaces and the material is anodised. Un-anodised material may be reheat treated only once in an air furnace.

In the case of aluminium-coated alloys, because of the danger of diffusing the alloying constituents into the coating, one reheat treatment is allowed for material thicknesses from 20 to 16 S.W.G., two for thicknesses 16 S.W.G. to 10 S.W.G., and three for thicknesses over 10 S.W.G.

The soaking period at the solution-treatment temperature depends on the furnace, the type of alloy, the previous thermal or mechanical treatment to which the alloy has been subjected, and the size and shape of the parts being treated. This period is best found from practice, Table IV giving a general guide. The period is not very critical except for aluminium-coated alloys which, as mentioned above, are liable to lose their pure coating if heated too long and thus be less corrosion resistant. For this reason, these alloys should be soaked for the shortest possible time.

The normal method of quenching is to plunge the hot metal into cold water immediately. Any delay allows the $CuAl_2$ in solution to be precipitated at the grain boundaries, leading to inter-granular corrosion and hence brittleness. Distortion of the component due to unequal quenching of various parts can be reduced by attention to the angle at which the component enters the bath or by quenching in oil. However, oil quenching should not be used for metal heated in a salt bath owing to the danger of fire when hot nitrate makes contact with the oil.

Age hardening takes place shortly after quenching, and any cold working should be done within one to two hours of quenching if the component is left at room temperature. Most alloys reach their full strength after four or five days, but some reach it quicker than this and some slower.

The material is usually quite soft and ductile immediately after "Solution Treatment," and most forming operations can be done in this state. However, where the maximum degree of softness of the material is required, it is obtained by heating to the "Annealing" temperature.

"Annealing" consists of heating the alloy to a temperature at which re-crystallisation takes place. Hence the work-hardened alloys, which get their increased strength by distortion of the grain structure, may be softened by re-formation of these similar to the heat-treated alloys, which also get increased strength from cold working or strain hardening. Note that after cold working

Table I—CLASSIFICATION OF ALUMINIUM ALLOYS

WROUGHT ALUMINIUM ALLOYS

Class	Treatment	Form	Sub-form	Specifications
WORK HARDENING	AS WORKED (ROLLED FORGED etc)	Sheet & Strip		DTD 213A
		Forgings & Bars for Forging		DTD 297
		Tubes		DTD 440, DTD 186A
		Rivets		DTD 404
	ANNEALED	Sheet & Strip		BSS L46, DTD 182A
		Extrusions & Bars for Machining		BSS 386, BSS L44, DTD 297
		Tubes		BSS 385, DTD 310A, DTD 190
		Rivets		DTD 303
HEAT-TREATABLE	SINGLE HEAT-TREATMENT (NATURAL AGEING)	Sheet & Strip	Clad	BSS 2L38, DTD 390, DTD 610
			Uncoated	BSS 4L4, BSS 395, BSS 5L3, DTD 603
		Extrusions & Bars for Machining		BSS 477, {BSS 6L1, BSS 2L39}
		Forgings & Bars for Machining		DTD 443, DTD 147, DTD 150A, BSS 532, BSS 478, BSS 533, BSS 4L25, {BSS 6L1, BSS 2L39}
		Tubes		DTD 450, BSS 396, BSS 5T4, DTD 520, DTD 273
		Rivets		BSS 2L37, DTD 327
	DOUBLE HEAT-TREATMENT (ARTIFICIAL AGEING)	Sheet & Strip	Clad	BSS L47, DTD 546
			Uncoated	DTD 346, DTD 356, DTD 646
		Extrusions & Bars for Machining		DTD 423A, BSS 2L42, {DTD 130A, DTD 410}, {BSS L45, BSS L40}, DTD 364A, DTD 363
		Forgings & Bars for Forgings		DTD 128, DTD 246A, DTD 324, DTD 423A, DTD 184, {DTD 130A, DTD 410}, {BSS L45, BSS L40}, DTD 364A
		Tubes		DTD 460, DTD 464

NOTES—Specifications bracketed together relate to the same alloy but cover different ranges of bar sizes.
The bottom line gives the specification numbers arranged in order of tensile strength specified, and the alloy of lowest strength being placed at the top of each column.

has been carried out on a heat-treatable alloy that has been annealed, the $CuAl_2$ particles are not in their correct form and the component must again be *solution* treated to restore the correct crystallographic structure. Annealing temperatures and times are given in Table V.

TABLE II

CONDITIONS FOR "SOLUTION TREATMENT" OF WROUGHT ALUMINIUM ALLOYS

Specification Numbers	*Form*	*Temperature Range* [1] (° C.)	*Quenching Medium*
B.S.S. 5L3	Sheet and strip	485–505	Water or oil
B.S.S. 395	" " "	470–490	" " "
D.T.D. 346	" " "	510–520	" " "
D.T.D. 356	" " "	500–520	" " "
D.T.D. 603	" " "	500–510	" " "
D.T.D. 646	" " "	500–510	" " "
B.S.S. 2L38	Aluminium-coated sheet and coils	485–505	" " "
B.S.S. AL47	" " " " "	500–515	" " "
B.S.S. BL47	" " " " "	525–535	" " "
D.T.D. 390	" " " " "	480–500	" " "
D.T.D. 546	Aluminium-coated sheet	500–510	" " "
D.T.D. 610	" " "	500–510	" " "
B.S.S. 396	Tubes	470–490	" " "
B.S.S. 5T4	"	485–505	" " "
D.T.D. 220A	"	525–535	" " "
D.T.D. 273	"	480–500	" " "
D.T.D. 450	"	520–530	" " "
D.T.D. 460	"	520–530	" " "
D.T.D. 464	"	495–520	" " "
D.T.D. 520	"	485–505	" " "
B.S.S. 2L37	Rivets	485–505	" " "
D.T.D. 327	"	480–500	" " "
B.S.S. 6L1, 2L39	Extrusions [2] and forgings	485–505	" " "
B.S.S. A2L40, AL45	" " "	500–515	" " "
B.S.S. B2L40, BL45	" " "	525–535	" " "
D.T.D. 364A	" " "	500–520	" " "
D.T.D. 423A, 443	" " "	520–530	" " "
D.T.D. 130A, 410	" " "	515–535	" " "
B.S.S. 2L42	Forgings	510–535	Water
B.S.S. 532	"	480–490	Water or oil
B.S.S. 533	"	505–520	" " "
D.T.D. 147	Airscrew forgings	470–490	" " "
D.T.D. 150A	" "	485–505	" " "
D.T.D. 184	" "	525–535	Water
D.T.D. 246A	Crankcase forgings	515–525	Cool in air
B.S.S. 4L25	Bars for forging and forgings	490–525	Water or oil [3]
D.T.D. 324	Forgings	520–535	" " "
D.T.D. 363	Extrusions [2]	450–470	" " "
B.S.S. 477	Bars	480–490	" " "
B.S.S. 478	"	505–515	" " " [3]

[1] These temperatures are average for alloys covered by the specification, and in cases of doubt reference must be made to the supplier.

[2] Extrusions = bars for machining or forging and extruded sections.

[3] Hot water may be used to reduce distortion.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This Table shows the value of K, which must be calculated from $\frac{D}{l}$.

$\frac{D}{l}$	K	$\frac{D}{l}$	K
4·0	0·3654	1·25	0·6381
3·75	0·3743	1·00	0·6884
3·5	0·3944	0·90	0·7110
3·25	0·4111	0·80	0·7351
3·0	0·4292	0·70	0·7609
2·75	0·4545	0·60	0·7885
2·5	0·4719	0·50	0·8181
2·25	0·4972	0·40	0·8499
2·0	0·5255	0·30	0·8838
1·75	0·5579	0·20	0·9201
1·5	0·5950	0·10	0·9588

Inductive Reactance

Calculated from the formula $2\pi f L$, where f = frequency and L = the inductance.

Capacity of Variable Condensers

$$C = \frac{0{\cdot}0885NS}{1{,}000{,}000d}$$

where N = Number of moving vanes.
S = Area of one moving vane in square centimetres.
d = Air gap between moving vanes and fixed vanes in centimetres.

H.F. Transformer Ratio.—$(n)n^2 = \frac{R}{R_0}$

R being the dynamic resistance of the tuned circuit and R_0 the A.C. resistance of the valve.

Stability in Screen-grid Stages

One Stage

Stable if $\frac{\omega\ g\ Co}{\sigma_1(\sigma_2 + \sigma v)}$ is less than 2.

where Co = residual anode-grid capacity in farads
$= 0{\cdot}001 \times 10^{-12}$ approx.
$= 0{\cdot}0045 \times 10^{-12}$ approx.
σ_1, σ_2 = conductance of grid and anode* circuits respectively
= 1/R where R = dynamic resistance in ohms.
σv = anode filament conductance of valve
$= 1/R_0$.

* In the case of transformer coupling, or its equivalent, replace σ_2 by $n^2\sigma$, where n = transformer ratio, σ = conductance $\left(= \frac{1}{R}\right)$ of tuned secondary.

Two Stages

Assuming identical tuned circuits throughout, and ignoring damping effects of valves on tuned circuits.

Stable if $\frac{\omega\ Co\ g}{\sigma^2}$ is less than 1·14 (tuned anode),

or if $\frac{\omega\ Co\ g}{\sigma^2}$ less than $1{\cdot}14n^2$ (tuned transformer),

where σ = Conductance of tuned circuit (secondary).
n = Transformer ratio.

Capacity of a Fixed Condenser

$$C = \frac{0{\cdot}0885\ AKN}{1{,}000{,}000d}$$

where K = Specific inductive capacity of dielectric.
N = Number of dielectrics.
A = Area of overlap of plates in square centimetres.
d = Thickness in centimetres.

Another formula:

$$C = \frac{AKN}{4{,}500{,}000d}$$

where A = Area of one plate in square inches.
K = S.I.C. of dielectric.
N = Number of plates minus one.
d = Thickness of dielectric in inches.

Ohm's Law

For D.C.

$$I = \frac{E}{R}$$

Watts dissipated

$$= I^2R = EI$$

$$= \frac{E^2}{R}.$$

For A.C.

$$I = \frac{E}{Z} \text{ where } Z = \text{impedance of circuit.}$$

Watts dissipated

$$= I^2R$$

$$= EI \cos \phi$$

where ϕ = phase angle between E and I.

Capacity of Condensers in Parallel

$$C = C_1 + C_2.$$

Capacity of Condensers in Series

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{C_1C_2}{C_1 + C_2}.$$

Resistances in Parallel

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1R_2}{R_1 + R_2}.$$

Resistances in Series

$$R = R_1 + R_2.$$

Resistance, Capacity, and Inductance in Series

Resulting Impedance.

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} = \sqrt{R^2 + X^2}.$$

Reactance of Coil

$$2\pi fL.$$

π, 3·14159; f, frequency; L, inductance in henrys.

Reactance of Condenser

$$\frac{1}{2\pi fC}.$$

C, capacity in farads.

Net Reactance

$$X = X_L - X_C.$$

$$\text{At Resonance, } f = \frac{1}{2\pi\sqrt{LC}}, \text{ or } \omega^2 = \frac{1}{LC}.$$

Voltage Amplification

$$= \frac{\mu R_1 \times R_2}{R_1 + R_2}.$$

Resistance of a Tuned Circuit at Resonance (Dynamic Resistance)

$$R = \frac{L}{C \times r},$$

r being the equivalent series resistance.

Magnification of Tuned Circuit

$$m = \frac{\omega L}{r}.$$

Current in Series Circuit at Resonance

$$I_{res.} = \frac{E}{r}$$

where r is equivalent series resistance of circuit at wavelength concerned (high-frequency resistance).

Peak Separation (Band-pass Tuners)

$$P = \frac{\sqrt{\omega^2 M^2 - r^2}}{2\pi L} \text{ cycles (inductive coupling).}$$

$\omega = 2\pi f$; M, mutual inductance in henrys; r, equivalent series resistance of tuned circuit; L, inductance in henrys.

$$P = \frac{\sqrt{\dfrac{1}{\omega^2 C_m^2} - r^2}}{2\pi L} \text{ cycles (capacity coupling).}$$

C_m = coupling capacity in farads.

Inductance of Single-layer Coil

$$L = \pi^2 n^2 D^2 l k \times 10^{-3}.$$

L, in microhenrys; π, 3·14159; D, diameter in cm.; n = number of turns to the cm.; l, length in cm.; k, a factor depending upon the length/diameter ratio.

when $\frac{D}{l}$ =	0·1	0·5	1·0	2·0	3·0	4·0.
k =	0·96	0·82	0·69	0·526	0·429	0·365.

Amplification Factor (Mu or μ).

$$\mu = \frac{V_{a2} - V_{a1}}{E_g}$$

when E_g = the grid voltage applied to restore the anode-current reading produced by V_{a2}, to that flowing when the anode voltage was V_{a1}. V_{a1} and V_{a2} represent the anode voltages. The Mu can be expressed, therefore, as the ratio of change of anode volts to change of grid volts to produce a constant anode current; or

$$\mu = \frac{\text{Mutual conductance} \times \text{impedance}}{1000}$$

when mutual conductance is expressed in mA./volt.

Impedance (R_a).
$$R_a = \frac{\text{Change in anode volts} \times 1000}{\text{Change in anode current (mA.)}}$$
$$\text{or } R_a = \frac{\text{Amplification factor} \times 1000}{\text{Mutual conductance (mA./V)}}$$
$$\text{or } R_a = \frac{\text{Amplification factor}}{\text{Mutual conductance (amp./V)}}.$$

Mutual Conductance (g or " Slope ").
$$g = \frac{\text{Change in anode current}}{\text{Change in grid volts}}$$
expressed in mhos when the current is amperes, or milliamperes per volt if the anode current is quoted in milliamperes. For convenience, micromohs are more widely used than the unit mho. There are 1,000,000 micromohs in 1 mho, and 1000 micromohs to 1 mA./volt.

Voltage Stage Gain.—When considering voltage amplifying stages, the gain per stage can be calculated from :
$$\text{V.G.} = \frac{\text{Amplification factor } (\mu) \times \text{external load impedance}}{\text{External load impedance} + \text{valve impedance}}.$$

Bias Resistor.—The value of a bias resistor can be calculated from
$$R_b = \frac{E_g \times 1000}{I(\text{mA.})}$$
when R_b = value of bias resistor in ohms ; E_g = the voltage of the required bias, and I represents the value of the total H.T. current flowing in the case of a battery-operated circuit, or the H.T. current of the valve under consideration in the case of mains-type valves.

Voltage Dropping Resistors.—The value of these can be calculated from the same formula as above and can be rewritten :
$$R_b = \frac{E \times 1000}{I(\text{mA.})}$$
when E represents the voltage to be dropped and I the current flowing in the circuit. If, as in the case of mains voltage dropping resistors or line cords, the current is expressed in amperes, the multiplication by 1000 must be ignored.

Radiation Resistance.—$R = \frac{W}{I^2}$, where W = watts radiated and I = aerial current in amperes.

" Q " Factor.—The " Q " factor is the ratio of the reactance of a coil to its effective resistance. It is used to denote the " goodness " or efficiency of a coil, and is, therefore, indicative of the selectivity of a tuned circuit.

$Q = \frac{2\pi f L}{R}$, when R represents the total resistance, i.e. D.C. plus H.F.

METRIC PREFIXES

In this system all multiples and submultiples are decimal; multiples are expressed by Greek and submultiples by Latin prefixes.

Symbol	*Value*	*Name*	*Prefix*
$\mu\mu$	10^{-12}	billionth	micro-micro-
$m\mu$	10^{-9}	thousand-millionth	milli-micro-
μ	10^{-6}	millionth	micro-
m	10^{-3}	thousandth	milli-
c	10^{-2}	hundredth	centi-
d	10^{-1}	tenth	deci-
	1	one	uni-
dk	10^{1}	ten	deca-
h	10^{2}	hundred	hecto-
k	10^{3}	thousand	kilo-
	10^{4}	ten thousand	myria-
M	10^{6}	million	mega-

INDEX

B

C

F

G

H

M

N

Q

R

X

Y

Z

INDEX TO ADVERTISERS

(*f* means facing; *b* means between)